Impact of Surface Runoff from Opencast Coal Mines in the Ib Valley Basin and its Management

Dissertation submitted in partial fulfillment

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in

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by

Dhruti Sundar Pradhan

(Roll No. 614MN3001)

based on research carried out

Under the supervision of

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This is to certify that the work presented in this dissertation entitled ***Impact of Surface Runoff from Opencast Coal Mines in the Ib Valley Basin and its Management*** by ***Dhruti Sundar Pradhan***, Roll Number 614MN3001, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of ***Master of Technology (Research)*** in ***Mining Engineering***. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

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Declaration of Originality

I, *Dhruti Sundar Pradhan*, Roll Number *614MN3001* hereby declare that this dissertation entitled *Impact of Surface Runoff from Opencast Coal Mines in the Ib Valley Basin and its Management* presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section "References". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

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Abstract

Energy is needed for economic growth, for improving the quality of life and for increasing opportunities for development. Most of energy requirement is fulfilled by coal, accounting for nearly 60% of the commercial energy demand of our country. Nearly 86% of these coals are obtained from opencast coal mines, which occupy very large areas. Opencast coal mining activities are known to cause serious environmental pollution if proper preventive and control measures are not adopted. Contamination of surface water bodies due to surface runoff in monsoon is one such concern. In this work, an attempt has been made to assess the runoff generated during monsoon in the Ib valley basin, which hosts some of the major opencast coal mines of the country. The Ib river valley is endowed with a very rich coal field known as Ib Valley Coalfield, which is a part of large synclinal Gondwana basin of Raigarh-Himgir and Chhattisgarh coalfields, and constitutes the south-eastern extension of the Sone-Mahanadi master basin. There are five opencast coal mines in this basin viz. Lajkura, Samaleswari, Belpahar, Lakhanpur and Lilari OCP, which come under Jharsuguda district in the state of Odisha. During monsoon season, rain water falls in the entire quarry area, external OB dump, coal stock and siding etc. in the entire coal field. The runoff flows into or out of the mine depending upon its topological profile. The surface runoff of the region takes its natural course flowing through the OB dumps, coal stocks, workshops and railway sidings into the surrounding water bodies which finally meet with Ib river. The Ib River flows from north to south and finally drains into Hirakud reservoir. This water often contains high load of total suspended solid (TSS), total dissolved solid (TDS), and heavy metals, which contaminate the surface and ground water. Sometimes it is acidic in nature and pollutes the water regime if the coal seam contains high amount of pyritic deposit. Therefore, the quantification of surface runoff from the coalfield and the study of its impact are very significant in order to formulate an appropriate management strategy.

The present work deals with estimation of the runoff quantity during the monsoon season in a GIS interface. The surface runoff generated within the mine area and the sump capacity has been estimated by rational method. Visual interpretation of the DEM and flow direction maps generated in a GIS interface has helped us in understanding the behavior and direction of surface runoff because of the region's topography. It was found that Lajkura and Samleswari OCP have adequate sump capacity to store the surface runoff

generated during the monsoon. However, the other opencast projects do not have the storage capability to store the surface runoff within the mine premises. These mines need to create additional sumps; otherwise, sedimentation ponds of adequate dimension are required so that the suspended particles could be settled before the runoff is discharged to outside the mine boundary.

Additionally, water quality analysis was carried out to ascertain the quality of water within the mines as well as in the nearby areas. A number of water samples were collected from mine sumps, treatment plant inlet and outlet, mine discharges and nearby water bodies for the pre-monsoon and monsoon period. Analysis for Physical, chemical parameters and heavy metal content was carried out following the standard method given in APHA, 2012 and as per the CPCB guidelines. In general, the water quality of mine sump in most of the opencast mines are found to be within permissible limit for utilization in industrial activities like dust suppression, firefighting, irrigation of plantation, washing of HEMMs etc. It has been observed that there is increase in concentration of parameters like TSS, Oil and Grease in water samples collected in the monsoon season compared to the pre-monsoon quality. Most of the mine sump water is nearly neutral to alkaline in nature. However, the mine water of Lajkiura sump and Samaleswari south sump show strongly acidic characteristics. In most of the samples, the heavy metal concentrations are within the permissible limit as compared to effluent standards prescribed under Environment Protection Rules, 1986. But high concentration of selenium has been observed in some of the water samples, which have several health impacts on the human beings, animals as well as aquatic life.

It is expected that the outcome of the study will help the mine management to formulate an appropriate strategy for control of surface runoff generated during the monsoon. This will help to avoid the surface runoff being discharged to the nearby areas and their probable contamination. Moreover, there is huge water demand in the mining area to fulfill the daily requirement during non-monsoon period. Thus, with adoption of proper management strategy, the runoff generated during the monsoon could be stored within the mine premises and used throughout the year. The water could also be supplied to nearby areas for irrigation of agricultural land in the dry seasons. If possible, it can even be used to supplement drinking water with some treatment.

Keywords: Surface runoff, Ib valley basin, Opencast coal mines, GIS, DEM, Physical parameters, Chemical parameters, Heavy metals.

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List of Abbreviations

Although all the abbreviations used in this dissertation are defined in the text as they occur, a list of them is presented below for easy reference.

AMD	: Acid Mine Drainage
APHA	: American Public Health Association
ASTER	: Advanced Space Borne Thermal and Radiometer
BDL	: Below Detection Limit
BOD	: Biochemical Oxygen Demand
CHP	: Coal Handling Plant
CIL	: Coal India Limited
CN	: Curve number
COD	: Chemical Oxygen Demand
Cond	: Conductivity
CPCB	: Central Pollution Control Board
DEM	: Digital Elevation Model
DO	: Dissolved Oxygen
DTM	: Digital Terrain Model
EPA	: Environmental Protection Agency
EMP	: Environmental Management Plan
ETP	: Effluent Treatment Plant
GIS	: Geographical Information System
GPS	: Global Positioning System
GSI	: Geological Survey of India
HEMM	: Heavy Earth Moving Machineries
ICP MS	: Inductively Coupled Plasma Mass Spectrometry
IDW	: Inverse Distance Weighted
IMD	: India Meteorological Department
IWSS	: Integrated Water Supply Scheme
LULC	: Land Use/Land Cover
MCL	: Mahanadi Coalfields Limited
MDTP	: Mine Discharge Treatment Plant

MSL	: Mean Sea Level
NRCS	: Natural Resources Conservation Service
O&G	: Oil and Grease
OB	: Over Burden
OCP	: Opencast Project
REE	: Rare Earth Elements
RF	: RADIO Frequency
RL	: Reduced Level
SAP	: Sequential Alkalinity Producing
SPCR	: Soil Pollution Control Regulation
STRM	: Shuttle Radar Topography Mission
TDS	: Total Dissolved Solid
Temp	: Temperature
TIN	: Triangulated Irregular Network
TISAB	: Total Ionic Strength Adjustment Buffer
ToC	: Time of Concentration
TSS	: Total Suspended Solid
UH	: Unit Hydrograph
USDA	: United States Department of Agriculture
WETP	: Workshop Effluent Treatment Plant
WQI	: Water Quality Index
WHO	: World Health Organisations

Chapter 1

Introduction

1.1 Background and Motivation

Energy is needed for economic growth, for improving the quality of life and for increasing opportunities for development. Ensuring a continuous supply of clean energy to all is essential for nurturing inclusive growth, meeting the development goals and raising the human development index in our country that compares poorly with several countries that are currently below India's level of development (planningcommission.nic.in).

Most of energy requirement in our country is fulfilled by coal. It occupies a center stage in India's energy scenario because of the limited petroleum and natural gas reserves, ecological constraints on hydroelectric projects and radiation hazards from nuclear power plants. The importance of coal in India can be judged from the fact that it supports about nearly 60% of the commercial energy demand of our country. To fulfill the rising demand, through sustained programme of investment and greater thrust on application of modern technologies, it has been possible to raise the production of coal from a level of about 70 million tonnes at the time of nationalization of coal mines in early 1970's to 612.44 million tonnes in 2014-15 (Ministry of Coal, 2016).

Most of the coal production in India comes from opencast mines which contribute over 86% of the total production *(Annual report 2013)*. Opencast method of coal production is adopted due to its cost effectiveness, high recovery and comparatively better safety aspects *(Das, 2014)*. A number of large opencast mines of over ten million tons per annum capacity are at present in operation.

Mine excavations usually have a high water influx, either due to rainfall or to interception of ground water flows. This water is usually an unwanted feature of mining and the rate of its accumulation exceeds the rate at which it can be utilized for processing and dust suppression. Hence, the accumulated water has to be pumped out to avoid the submergence of the mining void and the working machineries. In this process of opencast mining, huge amounts of water are discharged on surface to facilitate the mining operation. Particularly, during rainy season there is an inrush of huge quantities of water which is also discharged to keep mine operational.

A large quantity of water is also required daily for the different mining operations viz. drilling, dust suppression, firefighting, washing of heavy earth moving machinery (HEMM), processing, metal recovery and meeting the needs of workers on site. The amount of water required by a mine varies depending on its size, the mineral being extracted, and the extraction process used.

During the monsoon, the rain water falls on the entire mining area, a part of it percolates downwards into the water table, the quantity depending upon the nature of strata, slope, and vegetation, small amount evaporates to the atmosphere and rest contributes to surface runoff. The surface runoff of the region take its natural course flowing through the OB dumps, coal stocks, workshops and railway sidings into the surrounding water bodies. This water often contains high load of total suspended solid (TSS), total dissolved solid (TDS), and heavy metals, which contaminate the surface and ground water (*Tiwary and Dhar, 1994).* Sometimes it is acidic in nature and pollutes the water regime if the coal seam contain high amount of pyritic deposit *(Tiwary et al., 1997).*

Rainwater runoff from the mining areas to the nearby water body can create serious pollution problems. The disturbed land or active overburden dumps piled up near the mine is usually highly susceptive to erosion and therefore huge quantity of silt is accumulated by the flowing water. A variety of other pollutants like particulate matters, oil and grease, unburnt explosives and other chemicals including toxic heavy metals may also be transported into the water bodies by the rain water. Rainwater is likely to permeate into the OB dumps and dissolve some toxic metals from the heap which may contaminate the water course. The problem becomes much more complicated when the dump contains pyritic waste which has potential to cause acid mine drainage (AMD). Though most of the coals in Ib valley coalfield have less than 1% Sulphur, still the problem of AMD has been noticed in few instances.

In the opencast mines, large number of mining machineries and vehicles are being used and thus almost every mine has its own workshop. Workshop effluents contain high amounts of oil and grease which are released during washing of the machineries. Sometimes spillage of oil and other toxic reagents do occur in these areas which ultimately affect the water regime (*Tiwary, 2001*).

Odisha has the vast coal reserves nearly 75 billion tonnes and contributes approximately 25% of total Indian reserve (301.56 billion tonnes) estimated by Geological Survey of India report as on 01.04.2014. In Odisha, coal deposits are distributed in Talcher, Ib Valley, and Basundhara Coalfields. There are 8 opencast projects in Talcher, 5 in Ib Valley and 2 in Basundhara coalfields respectively. Talcher region has total reserve of 51 billion tonnes whereas Ib valley and Basundhara regions have 24 billion tonnes. In terms of spatial spread of prognostical coal bearing area, the coalfields of the state of Odisha have about 2723 Sq.km area (www.mcl.gov.in). Mahanadi Coalfields Limited (MCL) has become the top coal producer in the country by producing a record 138 million tonnes of dry fuel in the financial year 2015-16, contributing 39 per cent to the incremental growth of Coal India Limited. Out of the total production, share of the opencast coal mines is more than 99%.

In the recent past, many more public outrages have been noticed due to contamination of water bodies by mining activities in both Talcher and Ib valley coal fields, particularly during monsoon season. This has also been reported in several public interest litigations in the Odisha High Court. Hence, detailed study of the quality and quantity of this runoff and its impact on surrounding environment is required in order to prevent its adverse impact. The estimation of the quality and quantity will also help in deciding the sump capacity that will be required to be created in case; it is not allowed to be discharged outside the mine boundary.

1.2 Objectives

Against the above background, the current research work has been planned with the following objectives:

1. Study of the Ib valley basin characteristics.
2. Assessment of surface runoff generated by opencast coal mines in the Ib valley and its environmental impact.
3. Assessment of quality of runoff.
4. Probable movement of surface runoff by using digital elevation model.
5. Suggestion of remedial measures for control of the adverse impact of surface runoff.

1.3 Outline of the Thesis

The research reported in this thesis broadly consists of six chapters and synopsis of each chapter is organized as follows:

Chapter 1:

This chapter describes the present scenario of the opencast coal mining in India and Odisha, use of water in mining allowed by runoff, sources of pollution by surface runoff from mines. The background and motivation along with aim and objective of the thesis to carry out the present research is also reported in this chapter.

Chapter 2:

This chapter presents a literature survey which has been designed to provide a summary of the earlier investigations involving the areas of interest. It provides the research findings of previous investigators on environmental impacts of coal mines on the surface water and groundwater quality, calculation of surface runoff and sources of pollution due to defaced topography in mines.

Chapter 3:

This chapter deals with the detailed study area viz. Geology, Topography and drainage, Ib valley basin characteristics and present scenario of mining practice in all opencast coal mines in the Ib valley basin.

Chapter 4:

This chapter presents the surface runoff and different methods for calculation of surface runoff. It represents mine wise surface runoff study from all five opencast coal mines in the Ib valley basin including estimation of surface runoff from each region and sump capacity and some recommendations for each mines.

Chapter 5:

This chapter describes the collection of water samples including the pre-monsoon and monsoon water quality of the water bodies within the mines as well as outside the mines in the Ib valley area and determination of various parameters viz. physical, chemical and heavy metals. It also includes mines wise water quality analysis results in a tabular form.

Chapter 6:

This chapter describes the discussion in order to the rain fall data analysis, mine wise surface runoff and sump capacity analysis and GIS based the concentration contour map for water quality analysis in the study area. It gives some general recommendations for the mine managements. It also provides the summary of the research investigation and outlines the specific conclusions drawn from the research findings. Further, it suggests some potential areas of application of this study and directions for future research.

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Chapter 2

Literature Review

Various researchers/organizations have carried out different studies regarding the assessment of surface runoff, its impact and its management in mining areas. Summary of the outcome of some relevant research work have been presented here.

Singh and Rawat (1985) studied the conditions of mine drainages in North Eastern India and found the water to be highly acidic. Some traces of harmful materials were also found in their investigation. This water was not suitable to be supplied to general public. The specific trace elements found from their study were arsenic, cadmium, chromium, copper, mercury, lead, zinc, manganese, aluminum, iron, nickel etc. Result of these studies indicated that lime neutralization was best method for the treatment. They noticed that by the action of some bacteria, the ferrous ion present in rocks is converted to ferric ion which is characterized by yellow and red colour of mine drainages.

Singh (1986) carried out some experiments regarding aggressiveness of Fe^{+3}, Cu^{+2}, SO_4^{-2}, Cl^- in acid mine water and concluded that corrosion rates were significantly increased by Fe^{+3} and Cu^{+2} and due to their reduction to Fe^{+2} and metallic Cu respectively.

Tiwary and Dhar (1994) investigated environmental pollution from coal mining activities in Damodar river basin. They found that the mine water and coal washery effluents affected the chemical quality of both ground and surface water to which it is pumped out. They also observed that the mine water contained high amount of $S0_4^{-2}$, hardness, and bacterial contamination whereas, coal washery effluent consisted of high TSS, Iron content and oil and grease.

Morin and Hutt (1997) studied the effect of lime on neutralization of acid mine drainage and concluded that it is not capable of readily increasing the pH much above 5 and also found that in treating AMD in anoxic limestone drains, final pH values could be achieved up to 6.5.

Tiwary (2001) investigated the environmental impact of coal mining on water regime. He studied the quality of acidic and non-acidic mine water and leachate characteristics of opencast coal mining OB dumps. He found the occurrence of pollutants such as TSS, TDS, oil and grease and heavy metal in the coal mining waste effluents.

Younger et al. (2002) studied the meteorological factors affecting run off. They concluded that the discharge of untreated mine waters after the flooding of working can lead to surface runoff pollution, pollution of over-laying aquifers, localized flooding, over-loading and clogging of sewers.

Singh and Jha (2002) analyzed various water samples from mine discharge treatment plant (MDTP) and workshop effluent treatment plant (WETP) including both inlet and outlet in Mahanadi Coalfields Limited (MCL), Odisha. They carried out coagulation analysis for removal of total suspended solid (TSS) and Oil and Grease and found that optimum dose for minimizing the turbidity values.

Chachadi et al. (2005) calculated surface runoff and aquifer recharge by using a water balance model 'BALSEQ' (developed at the national laboratory of Civil Engineering, Lisbon, Portugal) in the iron ore mining belt of North Goa region. They considered 10 watersheds covering with 190 km^2 for the study and found that grassland and forest lands have the maximum aquifer recharge. They used daily rainfall, monthly probable evapotranspiration, runoff curve number (CN) and maximum soil moisture and found that as the input parameters.

Akcil and Koldas (2006) observed that AMD is the major cause of water pollution. They found the cause of AMD to be the exposure of sulphide ions to water and air. Mine water was found to have high conductivity, high concentration of iron, manganese, aluminum, low pH, and low amount of toxic heavy metals. They found that acid generation is stimulated by temperature, pH, oxygen content, gas phase amount, chemical activity of Fe^{+3}, degree of saturation with water, surface area of exposed metal sulphides, chemical activation energy etc. They suggested the use of ditches for the diversion of surface water flowing towards the site of pollution, prevention of groundwater infiltration into the pollution site, prevention of hydrological water seepage into the affected areas, regulated placement of acid-generating waste and deep well injunction for contaminated ground water for the control of acid mine drainage.

Hayes and Young (2006) used the rational method for comparing peak-discharge computation and runoff characteristics in central Virginia. They estimated time of concentration and runoff coefficient from rational hydrograph method. Design estimates of drainage area, time of concentration and runoff coefficients were used to estimate the design storm peak discharge for 8 small basins ranging from 2.5to 52.7acre by Rational method. Data collected and analyzed for this study confirmed the non-uniformity of precipitation in time and space, and were evidence for the validity of the assumption that unsteady runoff conditions were generated from varied precipitation, overland flow, and subsurface stormflow.

Bud et al. (2007) studied the sources and consequences of water pollution due to mining activity at Baia Mare mining area in Romania. They observed that environmental problems were ignored; the interest was mainly focused on maximized production in that area. They concluded that after the sulphide alteration, mining waste waters become acidic with very low pH and resulted sulfates are solubilized and destroyed, so the acid water with high heavy metals content could reach natural rivers, phreatic aquifers, affect soil and vegetation in mining perimeters and contiguous areas.

Kar et al. (2008) studied the assessment of heavy water pollution in surface water. They studied up to 96 surface water samples from river Ganga in West Bengal throughout 2004-05 and determined the pH, Electrical Conductivity (EC), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Cadmium (Cd), Chromium (Cr), Lead (Pb) and Nickel (Ni). They found that among the substantial heavy metals themselves, a significant negative correlation was observed between Fe and Cr, whereas Ni exhibited a significant positive correlation with Mn and Zn.

Sharkh (2009) estimated the surface runoff taking ten years of rainfall data using Watershed Modeling System (WMS) with GIS in Wadi Hasca watershed located in the Hebron District south of the West Bank. He calculated the surface run off by rational method.

Jabari et al (2009) estimated the runoff by using SCS curve number method integrated with GIS for agricultural water shed in West Bank district of Palestine. They found the amount of runoff represents 7.3% of total annual rainfall in that area. They have taken rainfall amount and curve number for runoff estimation. The curve number is based on land use treatment, hydrologic condition, and hydrologic soil group.

Nas and Berktay (2010) provided an overview of present groundwater quality determined spatial distribution of groundwater quality parameters such as pH, electrical conductivity, Cl^-, $SO4^{-2}$, hardness, and NO_3^- concentrations and, mapped groundwater quality in the central part of Turkey by using GIS and Geostatistics techniques. ArcGIS 9.0 and ArcGIS Geostatistical Analyst were used for generation of various thematic maps and ArcGIS Spatial Analyst to produce the final groundwater quality map. An interpolation technique, ordinary kriging, was used to obtain the spatial distribution of groundwater quality parameters.

Tiri et al. (2010) studied the quality of water surface of Koudiat Medouar dam in Algeria. They analysed the water condition and the results revealed that surface water quality was mainly controlled by geology, agricultural uses, and domestic discharges. They also found that water is contaminated by traces of metals (iron, lead), and marked by high levels of nitrate, ammonium, and sodium due to urban pollution.

Baruah et al. (2010) carried out a number of experiments for prediction of acid mine drainage (AMD) and found that continuous leaching of acidic waste from the coal mining sectors is responsible for the AMD. An Environmental Management Plan (EMP) has been developed for management of AMD in high sulphur coal mines by simulation of AMD from various qualities of coal and waste. They also carried out various experiments to determine the Physico-chemical characteristics of raw Meghalaya coals.

Yenilmez et al. (2010) evaluated the pollution levels at an abandoned coal mine site in Turkey with the aided of ArcGIS 9.3. They observed that the surface runoff routes and topography of an area are important in the transport of contaminants from the mining area and GIS is useful in this studied that locating the highest possible contaminated areas. They assessed the contamination level based on the limit values stated in the Soil Pollution Control Regulation of Turkey (SPCR) and found that the site is contaminated with Cr, Ni, and Cu.

Sangita et al. (2010) described the general chemistry of acid mine generation, its impact on environment, different treatment techniques as remedial and control measures and future trend in treatment technology. They studied the disadvantages of limestone in active treatment and found a low cost material like fly ash zeolite to be an excellent material to treat AMD.

Baruah et al. (2010) carried out a number of experiments in Meghalaya for prediction of AMD and found that continuous leaching of acidic waste from the coal mining sectors leads to AMD. An Environmental Management Plan (EMP) has been developed for management of AMD in high Sulphur coalmines by simulation of AMD from various qualities of coal and waste. Sequential alkalinity producing (SAP) coupled with biological processes were found to be effective in controlling AMD and reducing TDS, conductivity, sulphate and toxic elements. A Sequential alkalinity producing (SAP) is a process containing chemical and biochemical methods has been developed for effective treatment of AMD.

Equeenuddin et al. (2010) observed AMD in several areas of the northeast part of India on geochemical characterization and described its impact on water quality of various creeks, river, and groundwater in that area. They concluded that coal and coal measure rocks in the study area show finely disseminated pyrite crystals. Secondary solid phases, resulted due to oxidation of pyrite, occur on the surface of coal, and are mainly consisting of hydrated sulphate complexes of Fe and Mg (copiapite group of minerals).

Gomes et al. (2011) studied the environmental effect of coal mining in Brazil at Sango watershed. They used digital elevation model to improve the accuracy of runoff directions, watershed delineation, and the transport of pollutants within the streams. They have considered land use, soil types, topography, and hydrology to quantify the relative load of pollutants. By using algorithm and geoprocessing tool they identified the affected zone.

Singh et al. (2011) studied a GIS based multidimensional concept for ground water quality index (WQI) to understand the suitability of groundwater for irrigation and drinking purpose and assessment of change in land use and land cover from the year 1989 by using Landsat data to year 2006 using LISS III satellite data. The change in land used land covered (LULC) was correlated with water quality data and it was found that the areas around which rapid urbanization, as well as industrialization, is taking place showed poor to unfit groundwater in terms of quality.

Singh et al (2011) studied the geochemistry of mine water including 92 water samples from different area in Jharia coal field. The investigation indicates that the mine water is highly contaminated and requires treatment before use. Weathering and ion exchange process plays important role for mine water chemistry.

Hadadin (2012) estimated the peak flow discharge by six different methods the storm water runoff. The main objective of the studied are to develop a simple regression analysis between peak flow discharges and catchment areas, estimate the flood after subtracting all the losses. He evaluated the reliability of six techniques to accurately estimate storm-water runoff and to evaluate the runoff that is required to design hydraulic structures such as bridges, culverts, and dams.

Idowu et al. (2013) focused on the determination and utilization of estimated quantity of surface runoff to determine appropriate locations and sizes of drainage structures that can handle the water flow adequately without endangering lives and property. They considered rational method for calculating the quantity of surface runoff because; this method is simple and good for relatively small watersheds. The method includes the determination of the locations and volumes of the drainage structures, Time of Concentration (ToC), Rainfall Intensity (I), Runoff Coefficient (C) and hence the estimated quantities of the surface runoff. They recommended that the size of drainage structure to be constructed should be at least 25% more than the estimated quantity of surface runoff in the affected watershed to avoid flooding.

Needhidasan and Nallanathel (2013) studied a scientific drainage system to catch the storm water and design drainage pattern in in Palayam area of Calicut City in Kerala, India. They observed that precipitation data, infiltration indices. In this study, Rational method has been effectively used to design the storm water drains.

Chandra et al. (2014) assessed the quality of water samples from different ponds, streams, mine sumps and nearby water bodies of Jharia coalfield. They collected water samples from different locations in monsoon, winter and summer season. To verify the level of pollution they compared physio-chemical properties and heavy metal concentration with Indian surface water quality standard (IS: 2296).Based on the different parameters assessed they calculated the Water Quality Index and that indicated the surface water is not suitable for use due to discharge of uncontrolled leachate of dump materials.

Manna and Maiti (2014) investigated consequences of the topographic deformations at Raniganj coal field in India. They used Geographical Information System (GIS) techniques, to generate contour and profiled them over the spoil dumps and excavated areas using fine resolution digital elevation data (Remote Sensing image).They found that spoil surface that remained for a long time in quarries contained acidic logged water and led to acid mine drainage and erosion of loose soil particle. It deteriorated the entire land, water system of the region.

Mohammad and Stefan (2014) assessed the environmental impacts of mining on the surface and groundwater quality as well the factors controlling these impacts. They found that the use of surface and groundwater in south of Bochum, Germany, were affected by abandoned coal mines. They also marked the pollution of ground and surface water by Fe, as a result of the oxidation of pyrite and marcasite, as well as the generation of AMD.

Tiwari et al. (2015) carried out extensive research on the hydro geochemical forms and groundwater in the West Bokaro coalfield. They collected 33 water samples from various mining areas and observed some physical parameter, chemical parameter, cations, anions and trace metals in West Bokaro coal field region. The experimental results revealed that the ground water is slightly acidic to alkaline in nature.

Manna and Maiti (2015) studied the change of surface water hydrology by opencast mining in the Raniganj coalfield area, India. They assessed the surface drainage paths and flow accumulation by channel networks from digital elevation remote sensing images using Arc Hydro Tools of Arc GIS software. The runoff from small basins was estimated using the US Soil Conservation Service Curve Number method and volume of excavation was calculated by using Satellite-based digital elevation data in Arc GIS software.

Sahu et al. (2016) studied both quality and quantity of surface runoff due to open cast coal mines in Talcher coalfield. They determined the surface runoff by using rational method. They calculated the capacity of sump from the area of each sump from mine plans and depth data. They found that the general parameters such as pH, total suspended solid, BOD, oil and grease have a substantial impact on water quality of nearby water bodies. They suggested some artificial rain water harvesting techniques for recharge the ground water of the surrounding mining area.

Singh et al. (2016) assessed different water quality parameters in Kobra coal field at Chattisgarh state in Central India. They found that the mine water of the Korba coalfield is mildly acidic to alkaline in nature. The mine water chemistry is dominated by Ca^{2+} and Mg^{2+} in cationic and HCO_3^- and SO_4^{2-} in anionic composition. Weathering and ion exchange processes are the major controlling factors for determining mine water chemistry. Higher concentrations of TDS, NO_3^-, Fe, Mn, Al, Ni, and Pb in some mine water samples make it unsafe for direct uses in domestic purposes.

Summary and Knowledge Gap in Earlier Investigations

Extensive studies of the literature from all available sources are related directly or indirectly with the present work. From the exhaustive studies, it is found that there is a huge knowledge gap as far as systematic and well-planned study of impact of surface runoff and its impact from opencast coal mining are concerned. The following points highlight some of these knowledge gaps:

- A lot of research investigations have been reported on environmental impacts of coal mining activities in different parts of the world.

- Many literatures focused on the general chemistry of acid mine drainage (AMD) generation, its impact on environment, different treatment techniques as remedial and control measures and future trend in treatment technology.
- Most of the available literature is connected with environmental impact of coal mining on water regime, leachate characteristics of opencast coal mining over burden (OB) dumps, assessment of the environmental impacts of mining on the surface and groundwater quality as well as the factors controlling these impacts.
- Available literatures focused on the estimation of the quantity of surface runoff by various methods and its utilization for different watersheds, but the studies on impact of surface runoff are very limited in India.
- Till now, very little work has been reported relating to the impact of surface runoff from opencast coal mining in India.

In view of the above knowledge gap, the present work has been undertaken to investigate the impact of surface runoff from opencast coal mines in the Ib valley basin and its management.

Chapter 3

Study Area

Ib valley is situated in the districts of Sambalpur, Jharsuguda, and Sundargarh within the state of Odisha. Major part of the coalfield, including the present coal mining belt, falls in Jharsuguda district. The almost virgin Gopalpur tract in north and north-west lies in Sundargarh district.

Ib-valley coalfield is a part of large synclinal Gondwana basin of Raigarh-Himgir and Chhattisgarh coalfields and constitutes the south-eastern extension of the Sone-Mahanadi master basin bounded within $21^0$30'00'' to $22^0$06'00'' N and $83^0$32'00'' to 84^0 10'00''E. The boundary between Mand-Raigarh and Ib Valley coalfield is administrative boundary of Odisha and Chhattisgarh states. There are five opencast (Figure 3.1) and five underground mines in the Ib valley basin. These five OCPs are Lajkura, Samaleswari, Belpahar, Lakhanpur and Lilari. The location and aerial extent of opencast coal mines in Ib valley are shown in the figure 3.1.

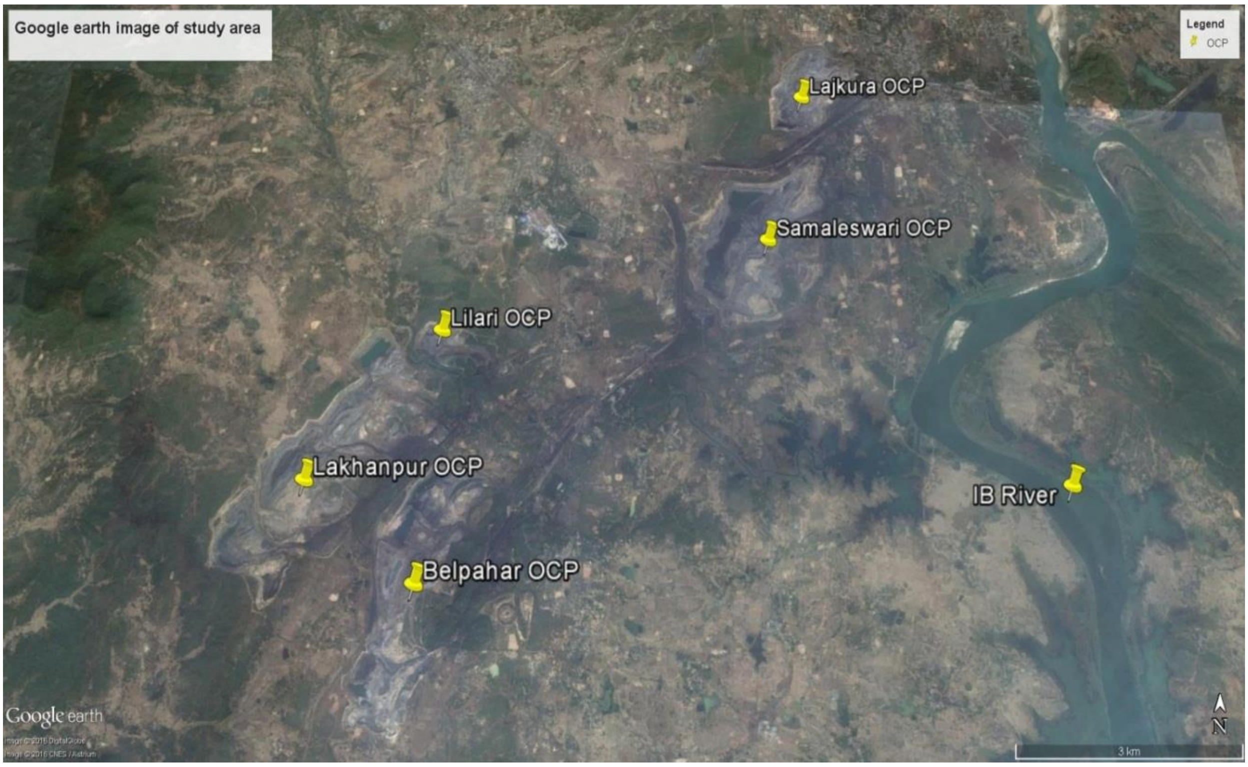

Figure 3.1: Location and aerial extent of open cast coal mines in Ib valley Coalfield

3.1 Geology

The Ib Valley coalfield forms a half elliptical basin. It is closed towards southeast and open towards north-west. The basin has normal contact with the metamorphic in the north-western, northern, north-eastern, eastern and southeastern part. It has a faulted contact with the metamorphic in the south-western boundary where younger formations viz. Raniganj and Barren Measure occur in juxtaposition with the metamorphic *(Senapaty, 2015)*. The coalfield is contiguous to Mand-Raigarh coalfield of Chhattisgarh. The major coal-bearing formations in Ib valley Coalfields are Karhabari and Barakar, through occurrence of coal seam in Raniganj formation has been reported by Geological Survey of India (GSI).The geological succession and geological map of Ib valley coalfield has been presented in Table 3.1 and figure 3.2 respectively. The geological succession of coal seams in the Ib valley coalfield is presented in Table 3.2.

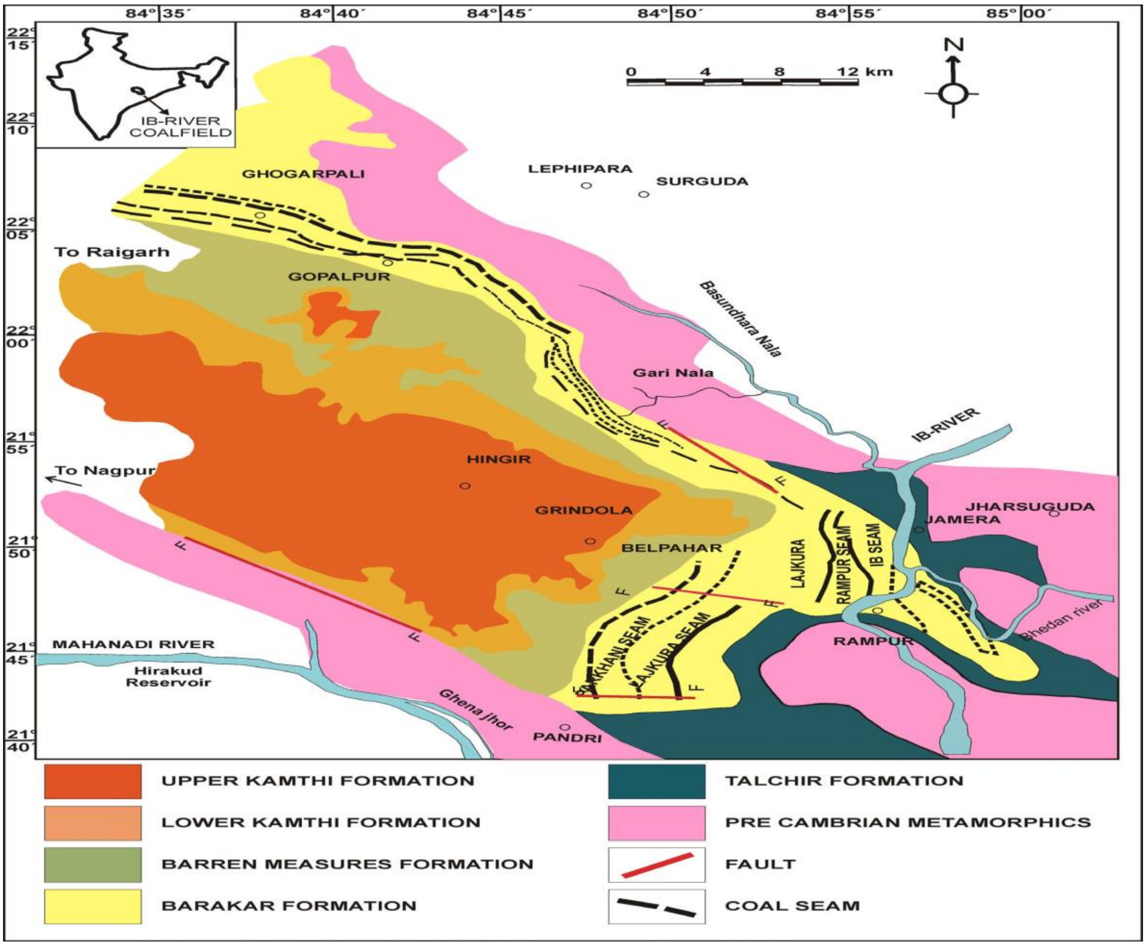

Figure 3.2: Geological map of the Ib valley coalfield area ***(Goswami, 2006)***

Table 3.1: Geological Succession of Ib Valley Coalfield (*Manjrekar et al., 2006*).

Age	Group	Formation	Lithology	Thickness(m)
Upper Permian to Triassic	**LOWER GONDWANA**	Kamthi (Upper) Kamthi (Middle) = Raniganj	Pebbly sandstone, ferruginous sandstone, and red shales Fine grade sandstone, siltstones, Coal Seams	>300
Middle Permian		Kamthi (Lower) = Barren Measures	Grey shales, carbonaceous shales, sandstones, clay and ironstones nodules	About 200
Lower Permian		Barakar	Grey sandstones, Carbonaceous shale, siltstone with thick coal seams and fire clay	575
Lower Permian		Karhabari	Black carbonaceous sandstone, peeble bed. Coal seams	90 – 125
Upper Carboniferous		Talchir	Diamictite, greenish sandstone, olive and chocolate shales, rhythmites	>130
……………………………………….Unconformity…………………………………………				
Precambrian	Granites, gneisses, schists, etc.			

Table 3.2: Succession of coal seams in the Ib valley coalfield *(Manjrekar et al., 2006).*

Seam/Coal horizon	Thickness range(m)	Remarks
BARAKAR		
Belpahar coal horizon	24-30	Highly interbanded coal section. In two sections in northern part. Generally considered as uneconomic.
Parting	105-195	
Parkhani coal horizon	0.5-1.0	Mostly shaly coal and carbonaceous shale
parting	92-120	
Lajkura seam	15-89	A persistent and highly banded horizon splits in 4 sections.
parting	16-112	
Rampur coal horizon	27-80	Highly interbanded, contains 5 to 6 sections.
parting	3-55	
KARHABARI		
Ib seam	2-10	Impersistent in northern part, splits up in 3 sections

3.2 Topography and Drainage

The coalfield has been divided in three sectors viz. Southeastern part (Rampur tract), northwestern part (Gopalpur tract), and west central part. The coalfield area is represented by low irregular upland of undulating topography and broadly can be divided into three different units:

i) Rugged topography - represented by hard metamorphic rocks all along the boundaries of the coalfield in the north, east and south.
ii) Low irregular plain country of rolling topography - represented by the rocks of Barakar formations.
iii) Hilly rough terrain - represented by the rocks of Kamthi formation including Barren measures and Raniganj formations. The altitude of the coalfield varies widely from less than 200m to more than 600m above MSL (mean sea level).

The general altitude varies between 200m and 350m. A series of low parallel ridges of sandstone interspaced with valleys of shales & coal seams are the characteristics of coal-bearing Barakar formations.

The drainage system of the coalfield is controlled by Ib river, a tributary of river Mahanadi. Ib river flows from north to south and discharges in Hirakud reservoir in the south-eastern fringe of the coalfield beyond the mining areas. The Pandern, Lilari, Basundhara, and Bagmara nallahs discharge into the river Ib and provide drainage system within the coalfield.

3.3 Ib Valley Basin Characteristics

The Ib river valley is considered as one of the most important industrial areas in eastern parts of India. This river completes a journey of about 252 km and waters an area of 12,447 sq km. The river starts in the hills nearby Pandrapet in Chhatisgarh at a height of 762 m. It flows through the districts of Raigarh and Jashpur, in the state of Chhattisgarh; and Jharsuguda and Sundargarh districts in the state of Odisha. Eventually, the river joins the Mahanadi, at the Hirakud dam in the state of Odisha.

The Ib river valley is endowed with a very rich coal field. The main parts of the Mahanadi coal fields are located on the banks of the Ib River. Ib River flows from north to south and drains into Hirakud reservoir. There are many tributary nallahs in the Ib valley coalfield and they finally meet with Ib river (Figure 3.3 and 3.4). Bagmara nallah flows on the northern side of the Lajkura mine which controls the drainage and feeder of Ib River. The Lilari nallah flows in between Lakhanpur OCP and Lilari OCP and continuing flow in the south block of Samaleswari mine and finally discharge into Ib river. One tributary of Lilari nallah namely, Pulijhore flows from west to east and finally mixed with Lilari nallah. The drainage of Lakhanpur mine is controlled by Lilari nallah which discharges into Hirakud reservoir (Figure 3.5). The drainage pattern of Belpahar mine is controlled by Lilari nallah which flows into the northern part of the mine and drains into Ib river. Pandern nallah flows near the Samaleswari mine and meet with Lilari nallah which finally discharges into Ib river.

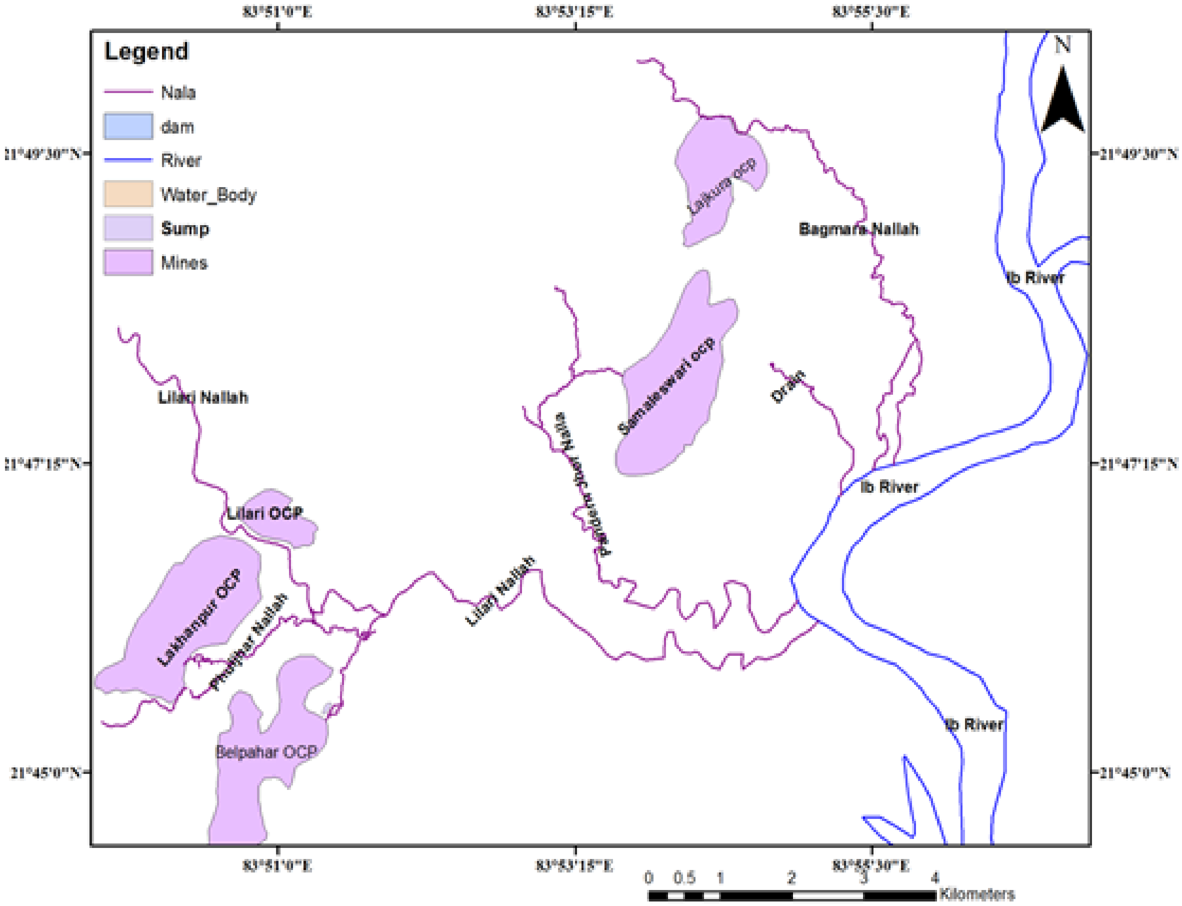

Figure 3.3: Location map of nallah, river, and mines in Ib valley coalfield

The above study makes it amply clear that any pollutant that is released from the opencast coal mining activities in the Ib Valley Coalfields will end up in the water streams of Ib river, and finally in Hirakud dam. Therefore, the quantification of surface runoff from the coalfield and the study of its impact is very significant in order to formulate an appropriate management strategy.

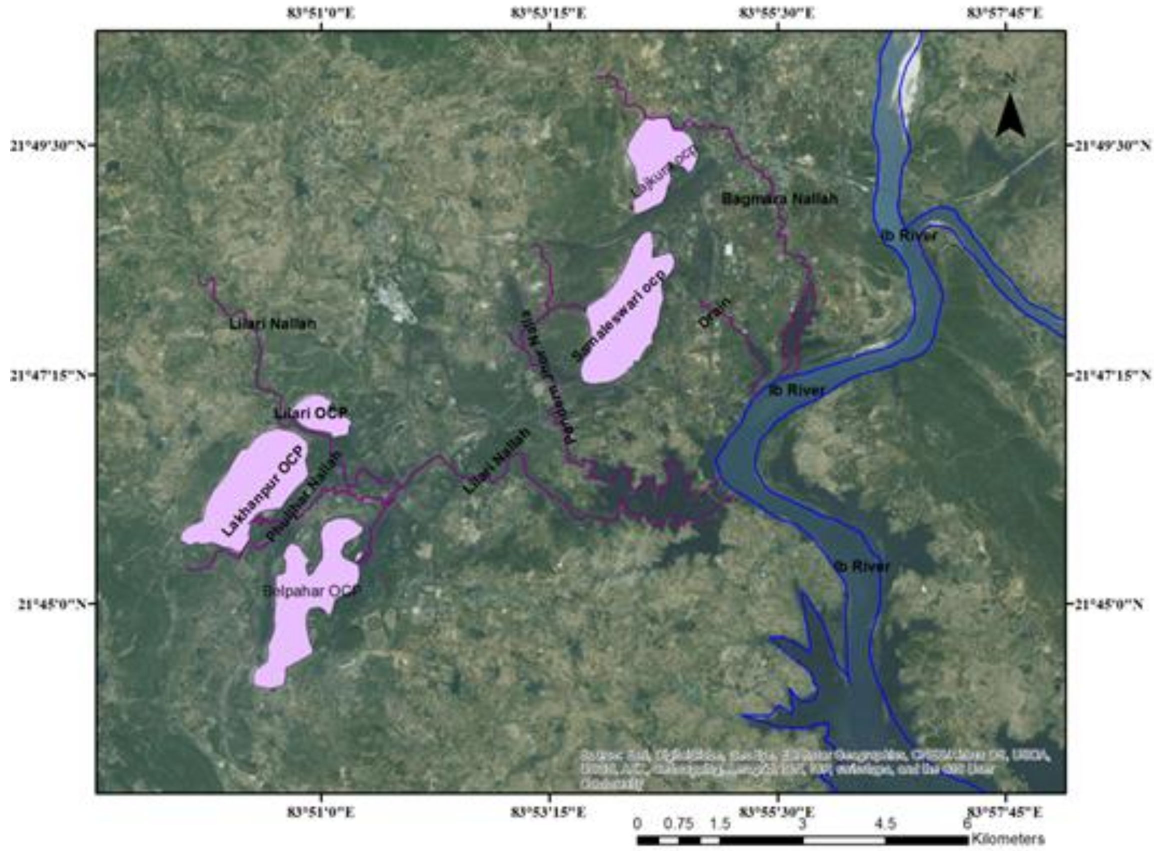

Figure 3.4: Location and aerial map of nallah and river in Ib valley with earth Imagery

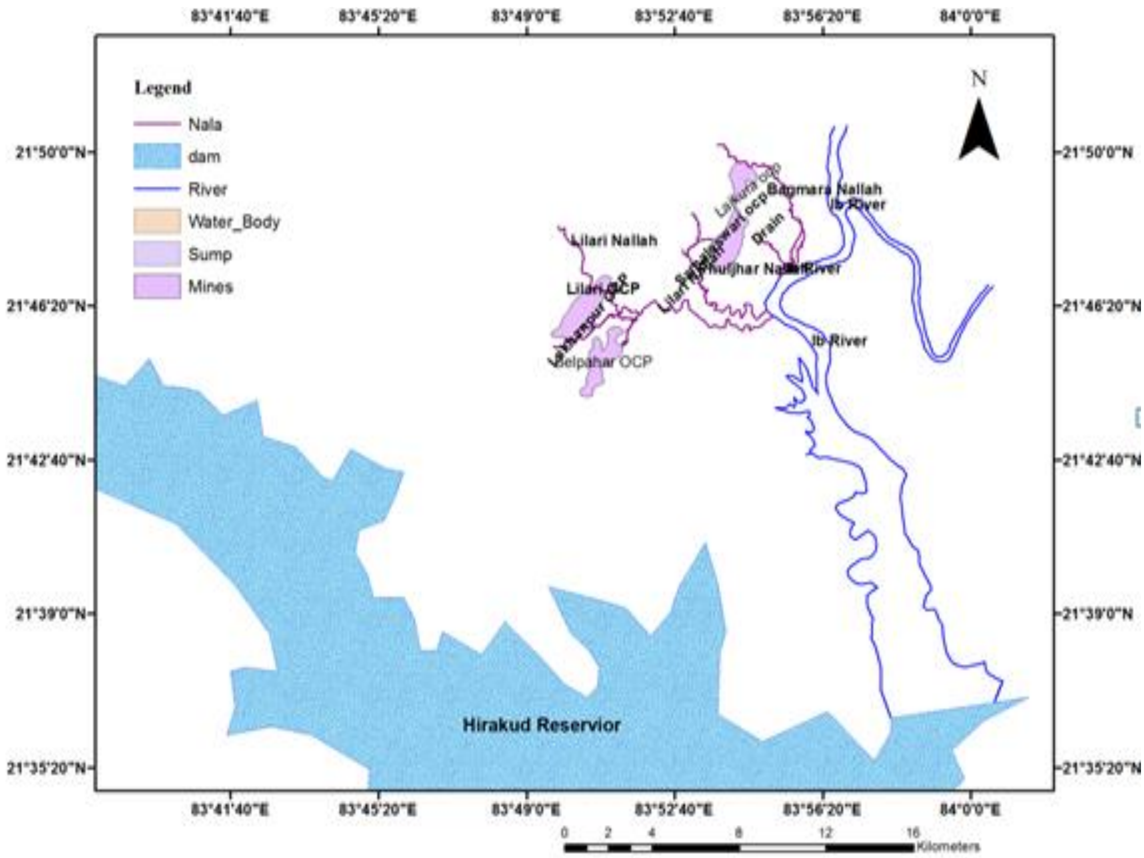

Figure 3.5: Location map of nallah and river with Hirakud reservoir.

3.4 Opencast Mining Practice in Ib Valley Coalfield

The mining method adopted in all five opencast coal mines comprises of two steps- removal of overburden and extraction of coal. Overburden removal is done by conventional shovel-dumper combination (drilling, blasting, loading through shovel and transportation through dumper) and also through use of dragline. Coal extraction is commonly done by surface miner, front end loader, and dumper. The coal is found at a depth of 12-22 m from the overburden. The height of coal benches is around 8m and width is around 15 m. The length of road is 3-4 km for coal transportation and about 1 km for OB transportation. The coal is transported from CHP to Railway siding by tippers. The coal winning is done through surface miner and transported by payloader and trucks (16 T tippers) combination. About 63 % coal winning is done by surface miner and 37% is done by shovel-dumper combination. Overburden removal is being done by deploying dragline, shovel-dumper combination both by departmental and contractual. The photographic view of the Samleswari opencast mine is presented in Figure 3.6.

Figure 3.6: View of Samaleswari opencast mine

Initially, OB is stored in external OB dumps and once sufficient space is created for constructions of Haul roads and Coal transportation roads with pliable gradient for movement of OB and coal from face to surface (Figure 3.7). Once the bottom most coal seam is extracted, the OB generated thereafter is utilized for backfilling of the opencast mining void. However, the quantity of OB generated in these coalfields is usually less than the void created and about 40 to 50% of the initial lands remain as the void.

Figure 3.7: View of overburden dump in Lajkura opencast mine

3.5 Current Runoff Management

During monsoon season, the rainwater that falls in the entire quarry area, external OB dump, coal stockyard etc. and accumulates in the mine voids. It was observed that accumulation of water in all the mine sumps. However, in a few cases where the water is accumulating in the coal face in dip side such as Lakhanpur OCP, pumping of water is being carried out to obtain a dry face for production operations. The water is being discharged to a sedimentation pond, the overflow of which goes to Lilari nallah.

Around the periphery of the quarry area, garland drains have been provided which diverts rainwater into the mine sumps. The water in the mine sumps, mainly collected during this rainy season, is being utilized for dust suppression, fire-fighting, plantation activities, washing of HEMMs in the mine workshop etc., and in some places, these are being used for supplementing the drinking water supply through Integrated Water Supply Scheme (IWSS). Also on the demand of nearby villagers, the water is being supplied to the nearby areas to support agriculture.

All the five opencast mines have workshops and effluent treatment plants (ETPs). The heavy earth moving machineries (HEMMs) like dumper, grader, crane, water tankers etc. are being washed at washing platform located in HEMMs workshop. The effluent generated during washing mainly contains TSS (Total suspended Solids) and Oil and Grease (O&G), these are directed to the workshops effluent treatment plant (WETP) or O&G Trap. Oil and Grease is recovered from the effluent through O&G Trap and is auctioned to the authorized agencies. TSS is removed regularly from the primary settling tanks. The treated clean water is collected in the clean water tank and then it is re-utilised for vehicle washing purpose.

Chapter 4

Surface Runoff and its Management

4.1 Surface Runoff

Surface runoff is a term used to describe when soil is infiltrated to full capacity and excess water, from rain, snowmelt, or other sources flow over the land. *(Idowu et al., 2012).* Runoff that occurs on surfaces before reaching a channel is also called overland flow. During monsoon season, the rain water falls in the entire quarry area, external OB dump, coal stockyard etc. A part of the water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage). In mining areas, large quantities of water get accumulated in the mining voids. Another part of the water evaporates into the atmosphere. The unbalanced amount of water flows along the surface depending upon the natural profile of the ground, and this is known as the surface runoff. There are many factors that can affect the surface runoff *(Subramanya, K. 1994).*

4.2 Factors Affecting Runoff

The main factors affecting the runoff from a catchment area are:

a) Precipitation characteristics
b) Shape and size of catchment
c) Topography
d) Geologic characteristics
e) Meteorological characteristics
f) Storage characteristics of a catchment

4.2.1 Precipitation Characteristics

Precipitation is the most important factor, which affects runoff. The important characteristics of precipitation are duration, intensity, and areal distribution.

Duration of total runoff depends on the duration of rainstorm. For a given rainfall intensity and other conditions, a longer duration rainfall event will result in more runoff.

Intensity of rainfall influences both rate and volume of runoff. The runoff volume and also runoff rate will be greater for an intense rainfall event than for less intense event.

Areal distribution also influences both the rate and volume of runoff. Generally, the maximum rate and volume of runoff occurs when the entire watershed contributes.

4.2.2 Shape and Size of Catchment

The runoff from a catchment depends upon the size, shape, and location of the catchment. The following are the general observations:

- More intense rainfall events are generally distributed over a relatively smaller area, i.e., larger the area lower will be the intensity of rainfall.
- The peak normally decreases as the area of the basin increase. (peak flow per unit area)
- Larger basins give a more constant minimum flow than the smaller ones. (effect of local rains and greater capacity of the ground-water reservoir)
- Fan shaped catchments give greater runoff because tributaries are nearly of same size and hence time of concentration of runoff is nearly same. On the contrary, discharges over fern leaf arrangement of tributaries are distributed over long period because of the different lengths of tributaries.

4.2.3 Topography

The runoff depends upon surface condition, slope, and land features. Runoff will be more from a smooth surface than from rugged surface. Also, if the surface slope is steep, water will flow quickly and adsorption and evaporation losses will be less, resulting in greater runoff. On the other hand, if the catchment is mountainous, the rainfall intensity will be high and hence runoff will be more.

4.2.4 Geologic Characteristics

Geologic characteristics include surface and sub-surface soil type, rocks and their permeability. Geologic characteristics influence infiltration and percolation rates. The runoff will be more for low infiltration capacity soil (clay) than for high infiltration capacity soil (sand).

4.2.5 Meteorological Characteristics

Temperature, wind speed, and humidity are the major meteorological factors, which affect runoff. Temperature, wind speed, and humidity affect evaporation and transpiration rates, thus soil moisture regime and infiltration rate, and finally runoff volume.

4.2.6 Storage Characteristics of a Catchment

Presence of artificial storage such as dams, weirs etc. and natural storage such as lakes and ponds etc. tend to reduce the peak flow. These structures also give rise to greater evaporation.

4.3 Different Methods for Runoff Calculation

There are various methods in existence for surface runoff calculation. These are Rational method, Modified Rational Method, NRCS methodology and Unit Hydrograph method. A general description of each method is provided below.

4.3.1 Rational Method

The Rational Method uses an empirical linear equation to compute the peak runoff rate from a selected period of uniform rainfall intensity. Originally developed more than 100 years ago, it continues to be useful in estimating runoff from simple, relatively small drainage areas such as parking lots. The Rational Method is widely used to estimate the peak surface runoff rate for design of a variety of drainage structures (*Size, D. A. 2004*). The rational formula expresses the relationship between peak runoff and rainfall as follows:

$$Q = C\ i\ A$$

Q = Peak discharge, Cubic meters per hour (m^3/h)
C = Rational method runoff coefficient
i = Rainfall intensity, mm/hour
A = Drainage area, hectares

4.3.2 Modified Rational Method

The Modified Rational Method is a somewhat recent adaptation of the Rational Method that can be used to not only compute peak runoff rates but also to estimate runoff volumes and hydrographs. This method uses the same input data and coefficients as the Rational Method along with the further assumption that, for the selected storm frequency, the duration of peak-producing rainfall is also the entire storm duration. Since, theoretically, there are an infinite number of rainfall intensities and associated durations with the same frequency or probability, the Modified Rational Method requires that several of these events be analyzed in the method to determine the most severe ones(*Size, D. A. 2004*).

4.3.3 NRCS Methodology

The USDA Natural Resources Conservation Service (NRCS) methodology is used method for computing storm water runoff rates, volumes, and hydrographs. It uses a hypothetical design storm and an empirical nonlinear runoff equation to compute runoff volumes and a dimensionless unit hydrograph to convert the volumes into runoff hydrographs. The methodology is particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs. The key component of the NRCS runoff equation is the NRCS Curve Number (CN), which is based on soil permeability, surface cover, hydrologic condition, and antecedent moisture. Watershed or drainage area time of concentration is the key component of the dimensionless unit hydrograph.

4.3.4 Unit Hydrograph Method

The Unit Hydrograph (UH) of a drainage basin is defined as a hydrograph of direct runoff resulting from one unit of effective rainfall which is uniformly distributed over the basin at a uniform rate during the specified period of time known as unit time or unit duration. The unit quantity of effective rainfall is generally taken as 1mm or 1cm and the outflow hydrograph is expressed by the discharge ordinates. The unit duration may be 1 hour, 2 hour, 3 hours or so depending upon the size of the catchment and storm characteristics. However, the unit duration cannot be more than the time of concentration, which is the time that is taken by the water from the furthest point of the catchment to reach the outlet.

4.4 Rainfall Data

Analysis of the rainfall data for any specific study area is of essential requirement in order to have a realistic assessment of the runoff and its management. With this objective, the rainfall data for a period of 15 consecutive years from 2000 to 2015 was collected and it has been presented in Table 4.1. (www.imdorissa.gov.in)
It was observed that the total annual average rainfall was 1316mm, and average rainfall during the monsoon period was1180 mm in Ib valley Coalfield. This was taken into consideration for calculation of surface runoff.

The monthly rainfall data from 2000 - 2015 were taken from Indian Meteorological Department and monthly average rainfall was calculated by taking the simple average. The average for monsoon was calculated by taking rainfall data from June-September.

Table 4.1: Month-wise Rain fall data in IB Valley coal field from 2000-2015

Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Monthly Average Rainfall(mm)
Jan	11.0	0.0	11.0	0.00	14.3	36.4	14.1	0.0	42.8	14.6	7.8	0.0	38.6	0.8	0.0	13.8	12.83
Feb	25.0	0.0	0.0	17.6	1.4	0.0	22.9	118.2	28.6	0.0	0.0	0.0	0.0	5.0	18.9	3.4	15.07
Mar	5.4	72.2	5.4	8.6	0.4	9.0	17.6	0.0	3.2	0.0	0.0	0.0	0.0	3.4	44.4	4.3	10.87
Apr	7.8	23.2	6.8	10.8	13.8	0.0	15.1	0.0	8.2	0.0	0.0	3.2	38.6	28.5	0.0	40.9	12.31
May	46.4	17.1	30.2	3.4	2.6	15.0	27.9	64.4	3.0	13.6	1.2	13.6	5.1	18.4	43.9	7.4	19.58
Jun	123.4	197.6	138.6	362.2	131.8	280.0	218.8	250.0	281.4	119	214.6	158.5	168.1	158.1	105.2	199.1	**194.15**
Jul	153.0	632.8	170.2	252.9	306.2	426.2	456.4	435.0	440.6	503.8	269.2	224.2	421.1	432.6	381.4	480.9	**374.16**
Aug	147.4	289.6	339.9	412.0	555.2	284.8	457.4	336.2	489.8	269.4	336.4	296.2	803.7	4.4	434.0	441.9	**368.65**
Sep	104.6	89.8	224.0	380.4	224.3	122.8	107.2	433.6	352.4	89.2	101.7	670.4	220.1	193.5	304.3	271.8	**243.14**
Oct	7.2	52.6	53.6	164.6	96.4	0.0	26.8	24.8	3.6	129.4	20.0	0.0	50.5	201.7	40.7	7.0	54.94
Nov	0.0	0.0	0.0	29.4	0.6	0.0	0.6	21.8	0.0	0.0	1.6	0.0	48.3	0.0	0.0	0.0	6.40
Dec	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.0	0.0	26.5	0.00	5.4	0.0	0.8	26.3	4.30

4.5 Calculation of Surface Runoff and Sump Capacity

Among all methods, Rational method is the simplest method to determine peak discharge from drainage basin because it is simple and good for relatively small watersheds Here, rational method is considered for this study. This method comprises the determination of the locations and volumes of the drainage structures, Rainfall Intensity (I), Runoff Coefficient (C) and hence the estimated quantities of the surface runoff. There are different meteorological and physical factors that affect the runoff viz. type of precipitation, direction of storm movement, temperature, wind relative humidity, season, soil type, land use, vegetation, elevation, drainage area, basin shape, reservoirs, Slope and Catchment type, ponds, lakes etc.

Runoff Coefficient (C)

The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land). The runoff coefficient used for the study is based on land-cover, topography, weather in natural or disturbed state and soil type within the study area. Generally, areas with permeable soils, flat slopes, and dense vegetation are expected to have the lowest value of coefficients. Areas with dense soil, moderate to steep slopes and sparse vegetation should have highest value. Furthermore, if types of soil cover are homogeneous for the entire watershed, then the average runoff coefficients is used. In a situation where there is multiple soil cover type in a watershed, the watershed will be divided into sections and the area calculated for each section. *(Kuichling,1889; Harlon,2007;and Idowu et al;2013)*

Rainfall Intensity (I)

Rainfall intensity is a measure of amount of rain that falls over time measured in millimeter. The intensity of rain is measured in the height of water layer covering the ground in a period of time. Time of Concentration is the time required for rainfall to reach the watershed lowest elevation from the highest elevation of the watershed. It is used as the duration of the storm for calculating quantity of surface runoff. Time of Concentration (ToC) of each rainfall is a determining factor for selecting rainfall intensity for each watershed *(Idowu et al. 2012.)*. Rainfall intensity that is equal to or slightly less than the

ToC is rainfall intensity that will have the full watershed contribution to the runoff at the outlet. Therefore, from the list of rainfall intensity that falls in a particular year, the one that is equal or slightly less than its ToC will be selected as the rainfall intensity that will be used in rational method for estimating quantity of surface runoff for the watershed.

4.5.1 Estimation of Surface Runoff

The surface runoff generated within the mine area and the sump activity has been estimated based on the present topographic condition, field investigation and data provided by mine. The drainage area has been estimated from the mine plan which acquired from the mining authorities. Visual interpretation of the DEM and flow direction maps generated in a GIS interface from the original mine plan. This will help us in understanding the behavior and direction of surface runoff because of the region's topography.

During monsoon season, rain water falls in the entire quarry area, external OB dump, coal stock and siding etc. The runoff flows into or out of the mine depending upon its topological profile. Since overburden removal, coal seam exposer, backfilling of overburden in the de-coaled void, extraction of coal and associated transportation activities are continuous process, and require a lot of space, the active quarry voids are not fixed or stationary. However, during the entire course of mining operations, mine sumps will always be present to accommodate the surface runoff, although its position may keep on changing from year to year due to advancing coal face and backfilling front. It is possible to maintain sufficient void spaces, because of low stripping ratio in Ib valley Coalfields. In some of the projects, it was observed that sumps of adequate sump capacity have not been created because of land acquisition problems. Water was being pumped out from these mines in order to create a free face for coal excavation. Thus the assessment of sump capacity of active quarry is indicative of the status during the study period only. The surface runoff generated within the mine area and the sump capacity has been estimated base on the present topographic condition, field investigations and the data provided by the mine authorities.

The surface runoff during monsoon period for each mine were determined by using the rational method which is quantified based on the following relationship:

Surface runoff (m^3) = Area × Total Rainfall during monsoon × Runoff Coefficient

The quarry area was determined from the scanned maps which were geo-referenced and digitized. Also, the boundary of the existing drainage networks and water bodies were digitized. The different layers of the digitized maps, water bodies, and drainage network were overlaid in ArcGIS 10.1 environment leading to the determinations of locations and areas of the water bodies.

Once the runoff is collected in the sumps, evaporation takes place throughout the year. Evaporation losses from the sumps for the monsoon period were taken into account to calculate the net quantity. The evaporation losses during the study were taken from the India Meteorological Department (IMD) observatory data at Hirakud Research Station.

Net quantity = Total Runoff – Evaporation losses

Moreover, a large quantity of water is required in each mine for dust suppression, firefighting, washing of HEMM etc. The water stored in the sumps during monsoon is used for these activities throughout the year. The water demand for each mine for the monsoon period was therefore deducted from the Net Runoff Quantity to determine the required sump capacity for the monsoon period. The water demand for the industrial activities was obtained from the officials of each mine.

Net Quantity of runoff to be stored during monsoon = Net Runoff Quantity – Water Demand

It is difficult to estimate exact capacity of sump. Hence, this was done by obtaining the area of each sump from the mine plans and Google Earth imagery. The depth information was obtained from the contour plans and also from survey officers of respective mines.

Sump capacity = Area ×Depth

4.6 Digital Elevation Model Preparation

For accurate depiction of the flow patterns in the mining areas, digital elevation models for the respective mines were prepared. A digital terrain model (DTM) represents the topography of the terrain surface for specific location on the Earth. This terrain surface can be represented as a combination of mathematical functions, vector-based triangulated irregular network (TIN) mesh or raster with height as it pixel value *(Li et al. 2005; Toppe, 1978)*. Among these three variants, the raster based DEM’s are highly popular and most widely accepted because of their simple data structure which makes them easily adaptable for mathematical calculations.

Elevation data obtained from various ground survey techniques, existing topographic maps, LIDAR, microwave or from stereo remote sensing methods is the key element for constructing a DEM (Nelson et al., 2008). At present, majority of these DEMs are constructed from microwaves /stereo remote sensing because of the lower cost per unit area. DEM from sources like Shuttle Radar Topography Mission (STRM), Advanced Space Borne Thermal and Radiometer (ASTER) and CARTOSAT are available for free cost. But on the flipside, they offer a very low spatial resolution which cannot be used by the mining industry for practical applications. Hence, to solve the real problem in mining industry, surface topography/elevation data from mine plan is necessary to form a raster based Digital elevation model.

4.6.1 Methodology

First, the mine plan was scanned. The scanned map was geo-referenced as per the Indian Coal Grid projection system. The elevation information was extracted by manual digitizing the height values from the geo-referenced plan and storing them in the attribute table. ArcGIS 10.1 was used to process these layers.

The surface topography / elevation in this plan are shown in the form of line features (contours lines) and point features (RL values, spot heights RL's of bore-holes). Out of these, the elevation sources can be re-classified as pre-mining elevation data and post mining elevation data. Contours and RL's of boreholes fall in the category of pre-mining elevation source as these elevation values will not be valid if the area has been affected by the mining activates. On the other hand, spot heights and point RL's fall in the category of post-mining elevation source as they are the elevation values of the surface as per the present condition. Hence, if the point whose elevation was to be extracted falls on area affected by mining activates, post-mining elevation was considered else pre-mining elevation was extracted to get a point shape file layer. A point shape file with elevation information for a particular mine has been shown in Figure 4.1.

A surface map was generated by interpolating the point shape-files. Since the points were randomly spread-out and clustered, kriging was selected as the interpolation method. This is the most cost effective method of generating a high resolution DEM for a mining area. The only limitation of this method discussed is the requirement of high density of elevation information at points which should be spread throughout the mining area; else the accuracy of the DEM will decrease. Even then the derived DEM is good enough to be used for any practical purpose.

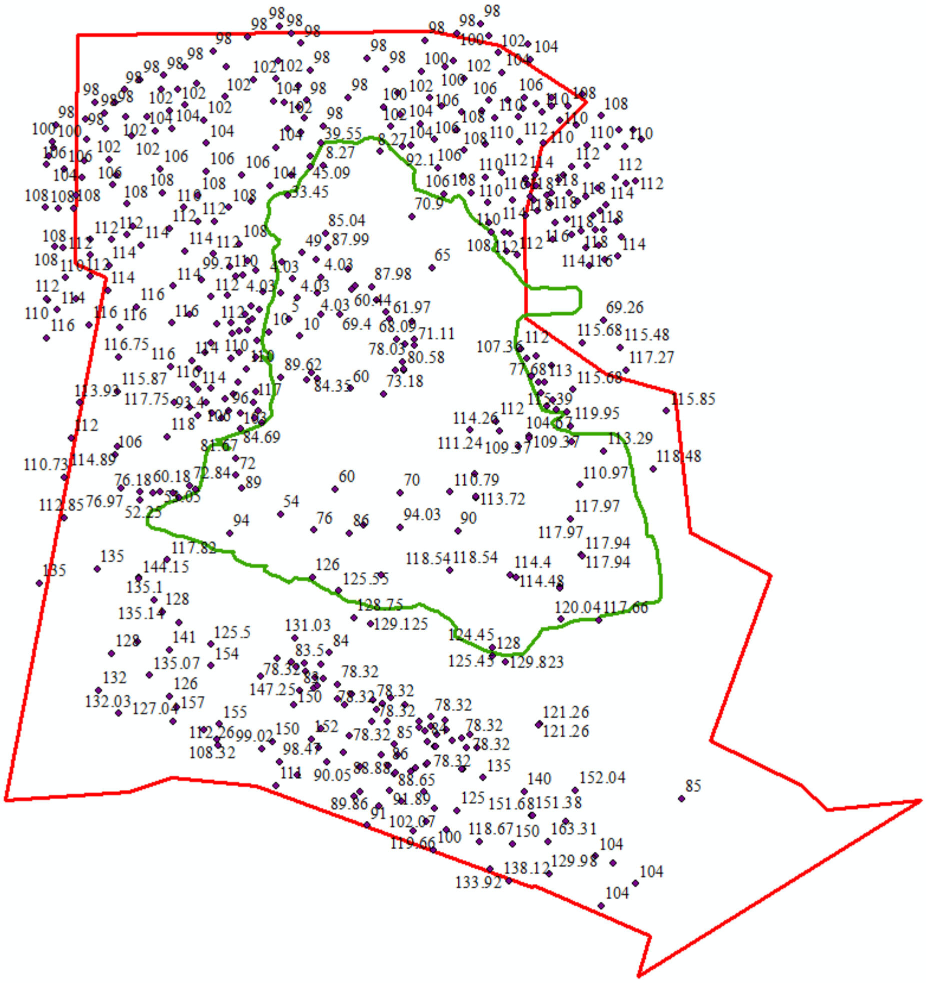

Figure 4.1: Point shape-file with elevation information

4.7 Mine Wise Surface Runoff Study

The detailed study of surface runoff calculation for all five open cast coal mines in the Ib valley basin has been discussed as follows.

4.7.1 Lajkura OCP

It lies between latitude 21^0 48' 39" to 21^0 49' 55" N and longitude 83^0 53' 15" to 83^0 54' 50" E. The mine is located towards the North of Samalesweri OCP as shown in Figure 4.2. There is an elevated railway line between the two mines; hence run-off from one cannot reach the other. But a culvert has been constructed to allow this flow of water. The area is generally flat barring hillock in the extreme dip side. The general slope of the area is towards north. Elevation of the area varies from 234 to 274m above MSL. Baghmara nallah flows on the northern side of the mine and controls the drainage.

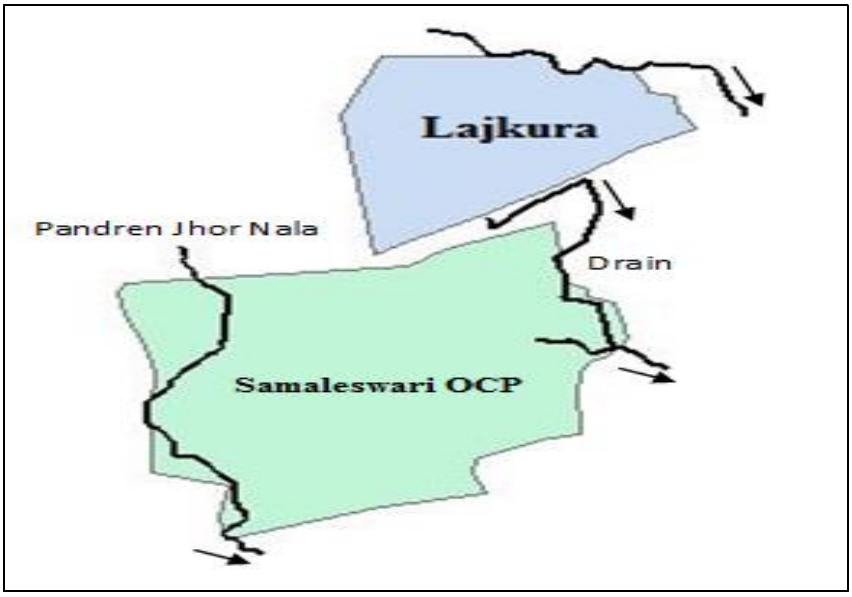

Figure 4.2: Lajkura and Samalesweri OCP

The DEM of the mine has been presented in Figure 4.3. Depending upon the flow patterns the area has been divided into 3 zones (R1 to R3). 3-D view of the DEM has been presented in Figure 4.4. The important surface features in the mining area have been presented Figure 4.5. Calculation of surface runoff and the sump capacity have been presented in Tables 4.2 and 4.3 respectively.

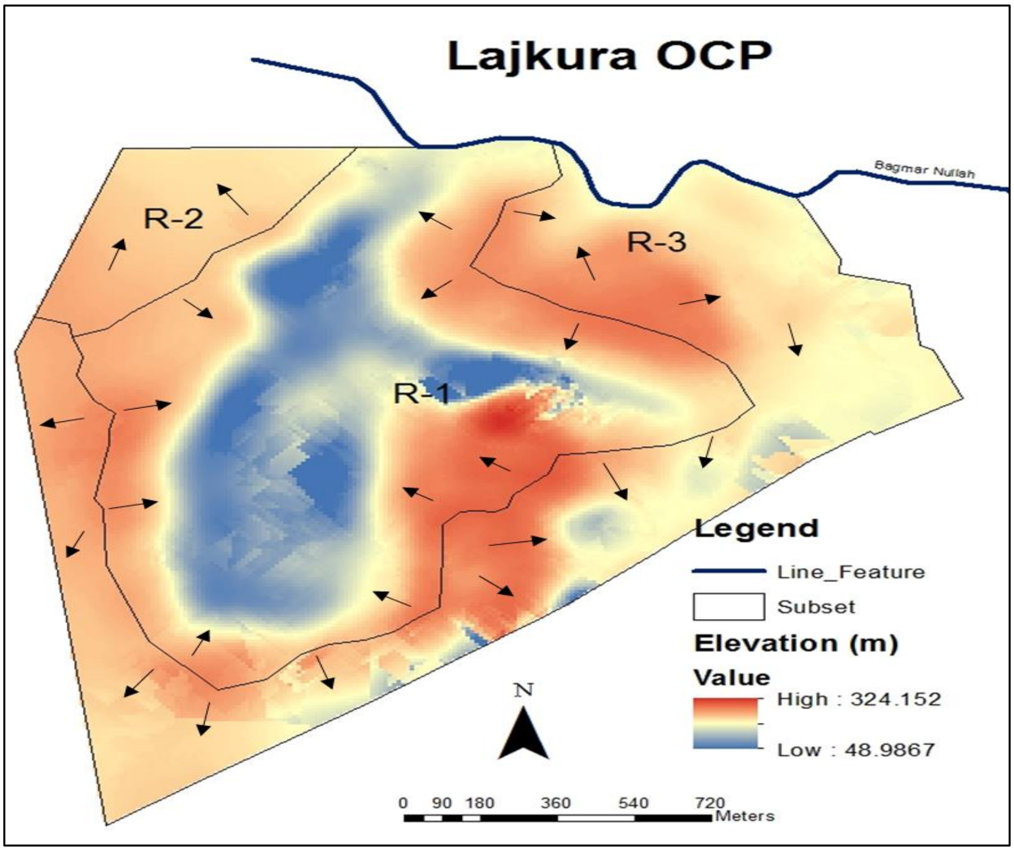

Figure 4.3: Digital Elevation Model of Lajkura OCP with arrows denoting the flow direction of water

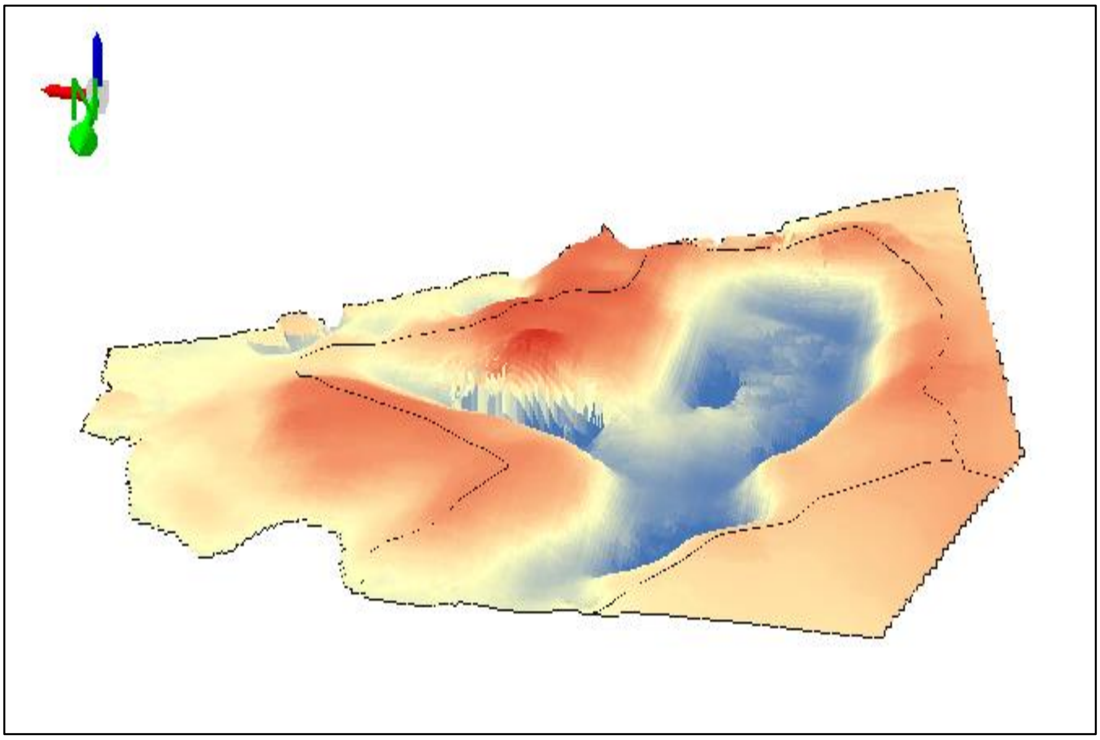

Figure 4.4: 3-D view of DEM of Lajkura OCP

Table 4.2: Surface runoff from each region in Lajkura OCP

Name	Area (m^2)	Rainfall (m)	Coefficient	Quantity (Lakh m^3)	Evaporation Losses (m^3)	Net Quantity (Lakh m^3)	Water Flow Direction
R1	1529281.71	1.18	0.8	14.43	0.38	14.05	Inflow
R2	496809.30	1.18	0.4	2.34		2.30	Outflow
R3	802939.91	1.18	0.6	5.68	0.02	5.66	Outflow
Total	2829030.92					**22.01**	

Monsoon consumption = 2.37 Lakh m^3

Net Quantity of runoff to be stored during Monsoon = 19.64 Lakh m^3

Table 4.3: Determination of sump capacity in Lajkura OCP

Sump Name	Actual Area (m^2)	Depth (m)	Volume (Lac m^3)
North Sump	57519	23	13.22
South Sump	42102	21	8.86
Sedimentation Tank	5000	5	0.25
		Total	**22.33**

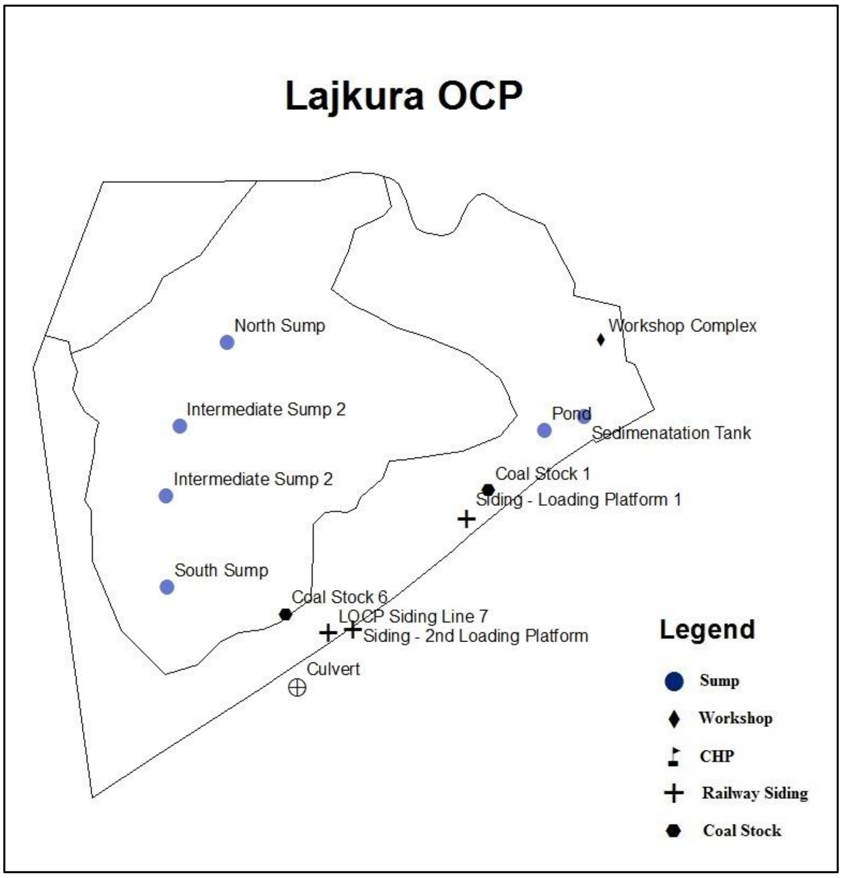

Figure 4.5: Location of important features in Lajkura OCP

Recommendations

It could be seen that the mine has adequate sump capacity to accommodate the surface runoff likely to be generated during the monsoon.

Presently the area between the north and south Sump is under excavation. In future, a new sump may be created in this region so that the water from North to South Sump can be accommodated to provide working face in either of using sump area.

Runoff from R2 which is flowing may be allowed to take its natural course as the region is in its natural state covered with thick vegetation.

Run-off from Workshop complex, Siding 1, Coal Stock 1 and eastern portion of R3 should be channelized into the existing sedimentation tank whose size needs to be enhanced to accommodate 14450 KL of water with a settling time of 4 hours with alum dosing. An online monitoring system may be installed to monitor the water quality if it discharged outside. Embankments of 1.5 meter height may be constructed on the southern banks of Baghmara nallah till the mine boundary to avoid the mixing of run-off

4.7.2 Samaleswari OCP

It is situated between latitudes 21^0 47' to 21^0 49' N and longitudes 83^0 53' to 83^0 55' E. The topography of the block is slightly undulating. The general slope of the area is towards south and south-west. The Lilari nallah flows in the south of the block. Ib River flows from north to south and drains into Hirakud reservoir. Rain water from ridge running in NNE-SSW direction flows to Pandren nallah and then to Lilari nallah, which finally discharges into Ib river. The surface elevation within the block varies from 218 to 257 m above mean sea level (MSL).

The DEM of the mine has been presented in Figure 4.6. Depending upon the flow patterns the area has been divided into 3 zones (R1 to R3). 3-D view of the DEM has been presented in Figure 4.7. The important surface features in the mining area have been presented in Figure 4.8. Calculation of surface runoff and the sump capacity has been presented in Tables 4.4 and 4.5 respectively.

Table 4.4: Surface runoff from each region in Samleswari OCP

Name	**Area (m^2)**	**Rainfall (m)**	**Coefficient**	**Quantity (Lac m^3)**	**Evaporation Losses (m^3)**	**Net Quantity (Lakh m^3)**	**Water Flow Direction**
R1	5065890.09	1.18	0.8	47.82	1.4	46.42	Inflow
R2	831383.97	1.18	0.6	5.88		5.88	Outflow
R3	1207108.32	1.18	0.4	5.69		5.69	Outflow
Total	**7104382.38**					**57.99**	

Table 4.5: Determination of sump capacity in Samaleswari OCP

Sump Name	**Actual Area (m^2)**	**Depth (m)**	**Volume (Lac m^3)**
North Sump	121605	21	25.53
Central Sump	179805	19	34.16
South Sump	71368.8	21	14.98
		Total	**74.67**

Monsoon consumption = 4.65 Lakh m^3

Net Quantity of runoff to be stored during Monsoon = 53.84 Lakh m^3

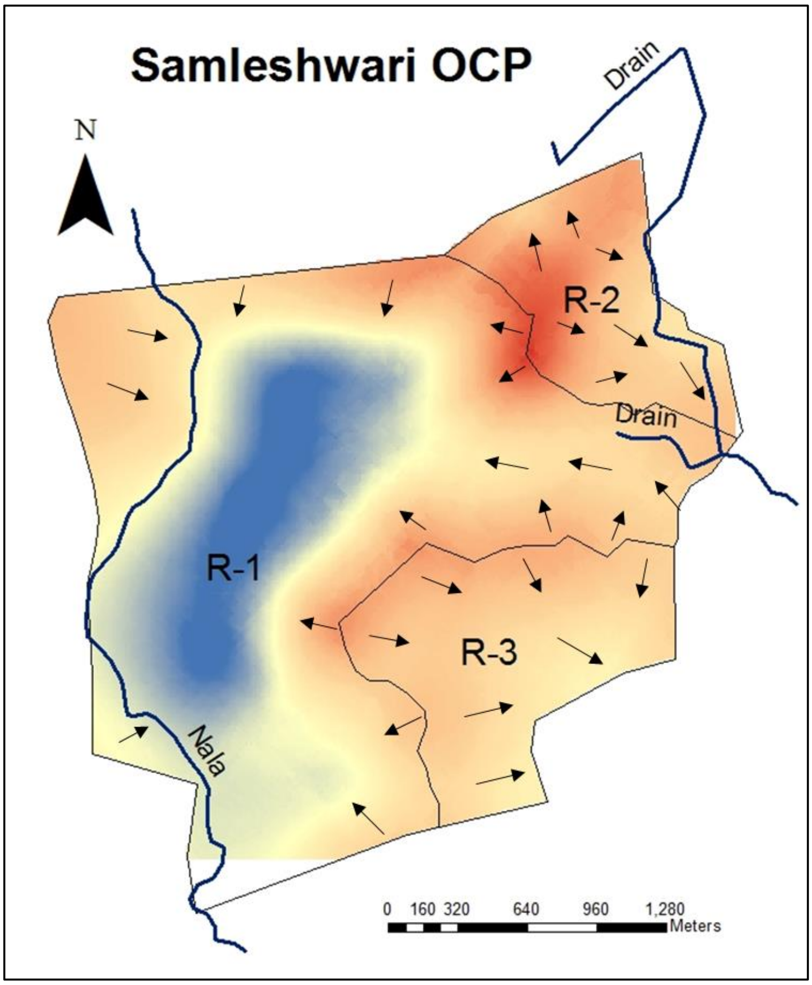

Figure 4.6: Digital Elevation Model of Samaleswari OCP with arrows denoting the flow direction of water

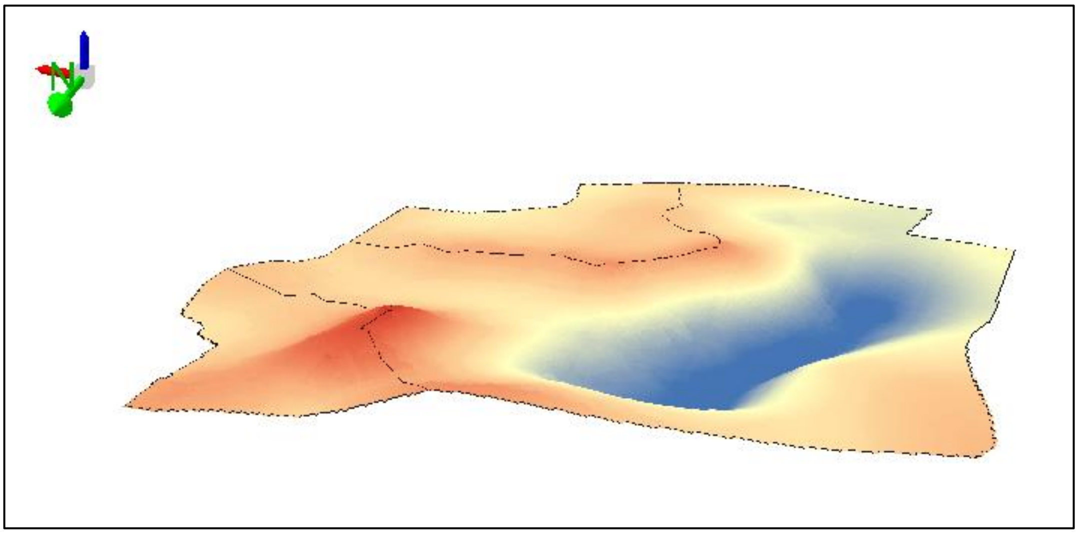

Figure 4.7: 3-D view of DEM of Samaleswari OCP

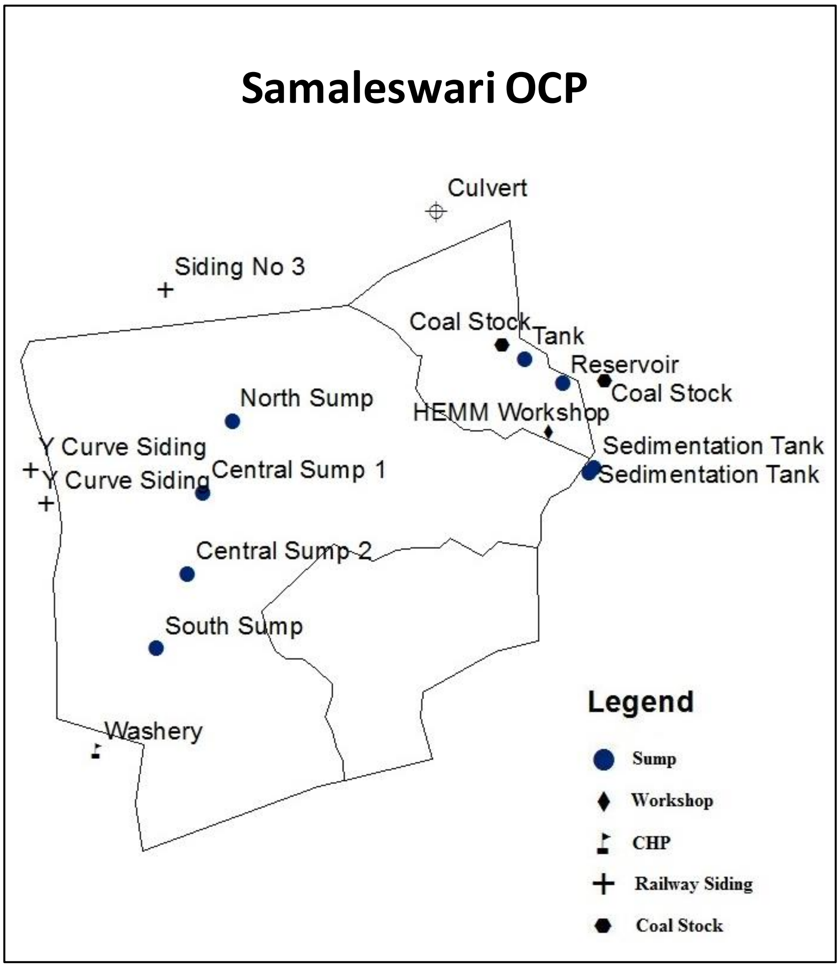

Figure 4.8: Location of important features in Samaleswari OCP

Recommendations

Although this mine has adequate sump capacity, the runoff from R2 and the coal stock is being channelized into the mine through garland drain. Adequate measures should be adopted to avoid clogging of the drain by making concrete lining, providing retaining walls for OB dump etc.

Presently run-off from Y-curve siding and washery is flowing into the Pandren Nallah which will be avoided after this nallah has been diverted. Hence, runoff from these areas can thereafter be channelized to the sumps in R1. Moreover, proper embankments can also be provided for the new channel to avoid run-off from mining areas flowing into the newly constructed nallah.

Pandern nallah can be redirected, if possible, to remove any chances of contamination

4.7.3 Belpahar OCP

Belpahar block is situated between latitudes 21^{0}42'20" to 21^{0}47'00" N and longitudes 83^{0}49'35" to 83^{0}53'00" E., In fact, there are three mines viz. Belpahar, Lakhanpur, and Lilari which are located very close to each other as shown in Figure 4.9. The general configuration of the Belpahar area is plain to moderately undulating, gently sloping towards east. The highest and lowest elevations of the area under report as per geological report are 237m and 195m above mean sea level respectively. The drainage pattern is mainly controlled by Lilari nallah which flows in the Northern part of the block and drains into Ib River to the east of the area.

The DEM of the mine has been presented in Figure 4.10. Depending upon the flow patterns, the area has been divided into 4 zones (R1 to R4). 3-D view of the DEM has been presented Figure 4.11. The important surface features in the mining area have been presented Figure 4.12. Calculation of surface runoff and the sump capacity has been presented in Tables 4.6 and 4.7 respectively.

Figure 4.9: Belpahar, Lakhanpur, and Lilari OCP

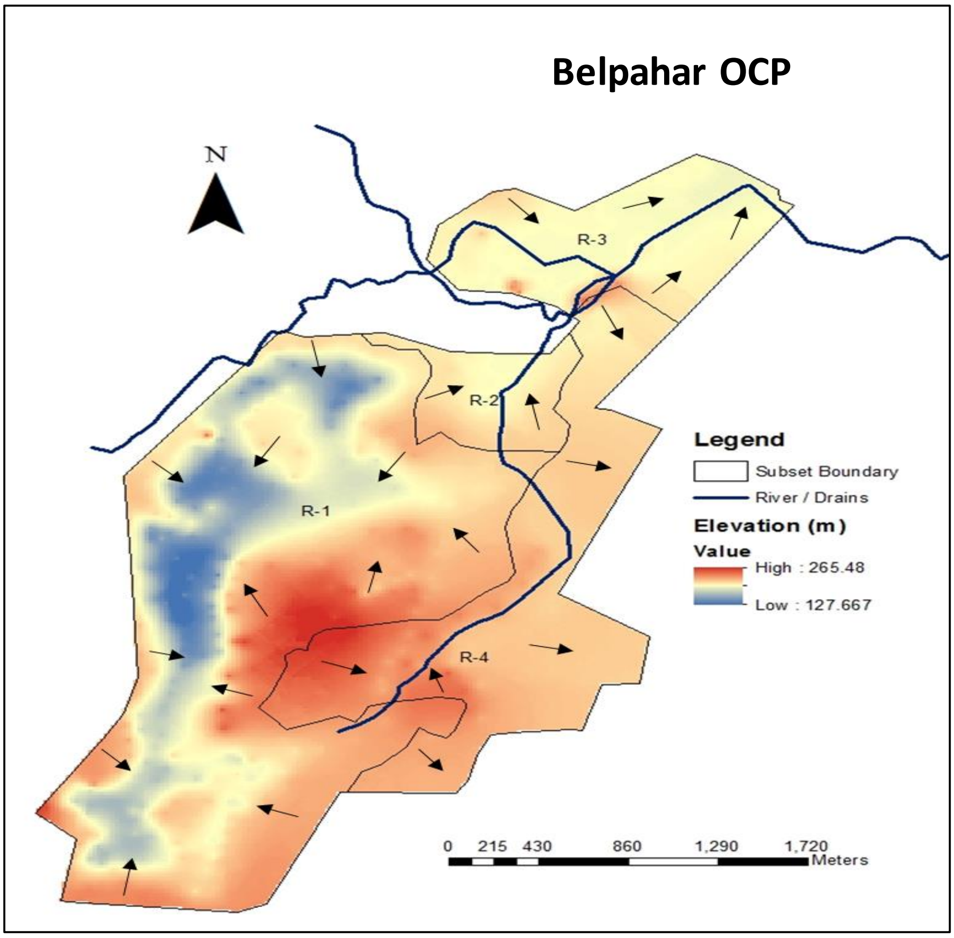

Figure 4.10: Digital Elevation Model of Belphar OCP with arrows denoting the flow direction of water

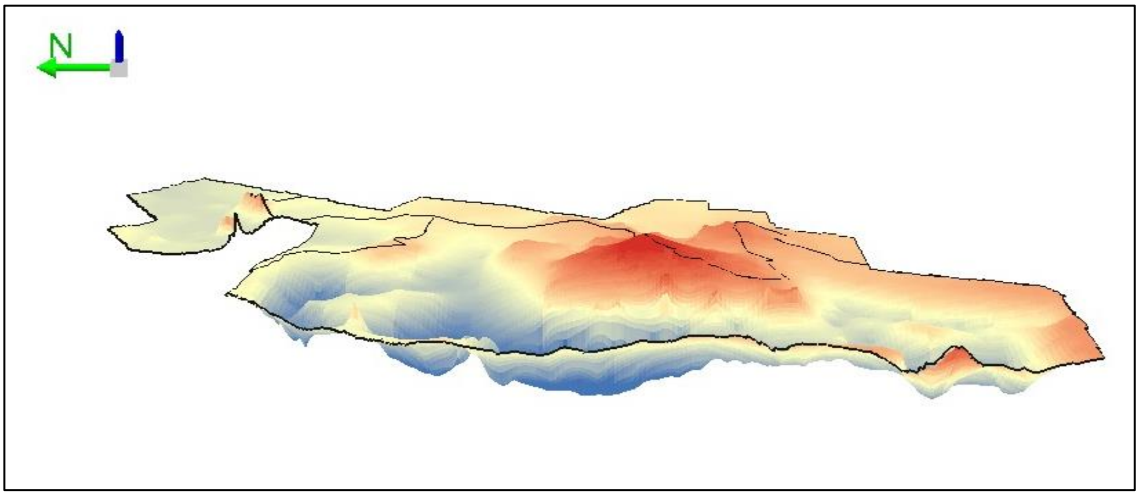

Figure 4.11: 3-D view of DEM of Belphar OCP

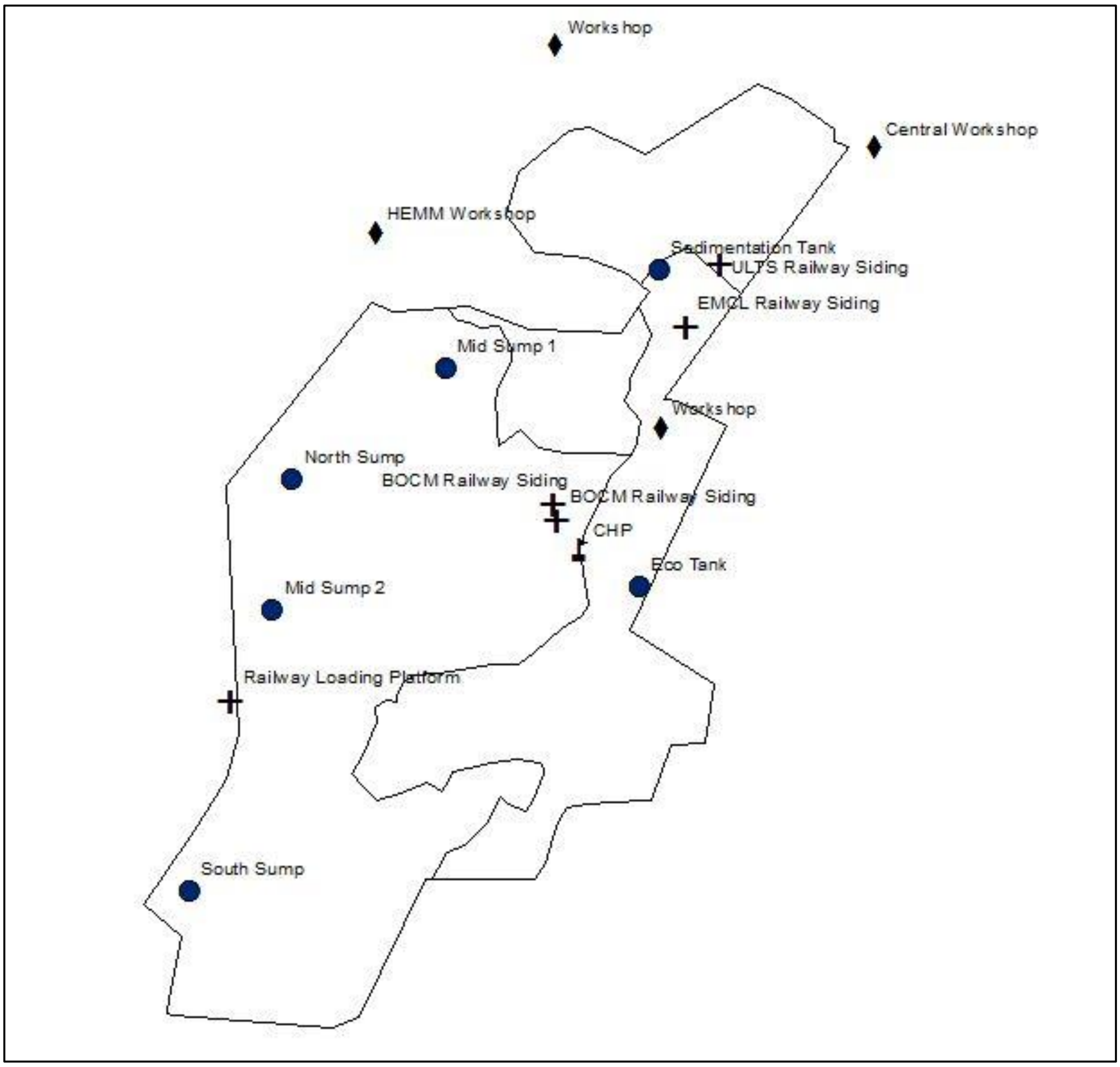

Figure 4.12: Location of important features in Belpahar OCP

Table 4.6: Surface runoff from each region in Belpahar OCP

Name	Area (m^2)	Rainfall (m)	Coefficient	Quantity (Lac m^3)	Evaporation Losses (m^3)	Net Quantity (Lakh m^3)	Water Flow Direction
R-1	4806168.15	1.18	0.8	45.37	0.62	44.75	Inflow
R-2	453635.82	1.18	0.4	2.14		2.14	Outflow
R-3	1096510.11	1.18	0.4	5.17		5.17	Outflow
R-4	2019019.22	1.18	0.6	14.29	0.78	13.51	Outflow
Total	**8375333.30**					**65.57**	

Monsoon consumption = 2.18 Lakh m^3

Net Quantity of runoff to be stored during Monsoon = 63.39 Lakh m^3

Table 4.7: Determination of sump capacity in Belpahar OCP

Sump Name	**Actual Area (m^2)**	**Depth (m)**	**Volume (Lakh m^3)**
North Quarry Sump	60904	12	7.3
South Sump	34666	14	4.8
Intermediate Sump 2	57667	18	10.37
Intermediate Sump 1	9420	12	1.13
Eco Tank	203475	5	10.17
		Total	**33.77**

Recommendations

R3 is in its undisturbed state; hence, the run-off can be allowed to take its natural course.

There is a huge difference between the expected runoff generated in the monsoon months and the storage capacity of the mines. Provisions should be made to increase the storage capacity/utilization to accommodate the extra 29.62 Lakh m^3 of runoff generated during the monsoon. Appropriate locations should be identified and new sumps should be created to store the runoff generated during the monsoon.

As the existing drain does not capture all the run-off from R4, a garland drain in the periphery of R4 may be constructed to channelize the runoff into the Eco Tank. Presently, the overflow from Eco Tank goes through a garland drain to the MDTP via Belpahar railway siding, where it mixes with the contaminated railway siding runoff. This overflow water should be routed directly to the MDTP discharge point or mining sumps without allowing further contamination.

An extra 8.14 Lakh m^3 of water can be accommodated by increasing the depth of Eco Tank to 8 m (Figure 4.13). In future, instead of discharging water from Eco Tank, it should be utilized by the proposed coal washery which has an annual requirement of nearly 10.0 Lakh m^3.

Figure 4.13: A view of the Eco Tank in Belphar OCP

The runoff from both the railway siding should be brought to the existing MDTP or the mining voids. The capacity of the MDTP should be of 10600 m^3 with a retention time of 4 hours with alum dosing.

The drain flowing between the OB dumps should be provided with soil and water conservation measures like gabion/retaining walls, coir matting, plantation etc. This drain should be of an adequate width and can be constructed with concrete linings

Lilari nallah is flowing through Belphar OCP, Lakhanpur OCP, and Lilari OCP. Also, there is a plan of integrating these three OCP's to extract the lower seams. Hence, to eliminate any risk of contamination of water and inundation of mines, the Lilari nallah may be diverted beyond the periphery of these mines.

4.7.4 Lakhanpur OCP

The block area falls between latitudes 21°42'15" N to 21°47'10"N and longitudes 83°48'11"E to 83°52'38"E. The topography of the block is plain to moderately undulating. The area is gently sloping towards east. The highest and lowest elevations of the area are 250m and 198m above mean sea level respectively. The drainage is controlled by Lilari nallah which discharges into Hirakud reservoir. One tributary (seasonal) of Lilari nallah namely, Pulijhore flows from west to east within the mine area with its catchment area to the west of the block.

The DEM of the mine has been presented in Figure 4.14. Depending upon the flow patterns the area has been divided into 5 zones (R1 to R5). 3-D view of the DEM has been presented in Figure 4.15. The important surface features in the mining area have been presented in Figure 4.16. Calculation of surface runoff and the sump capacity have been presented in Tables 4.8 and 4.9 respectively.

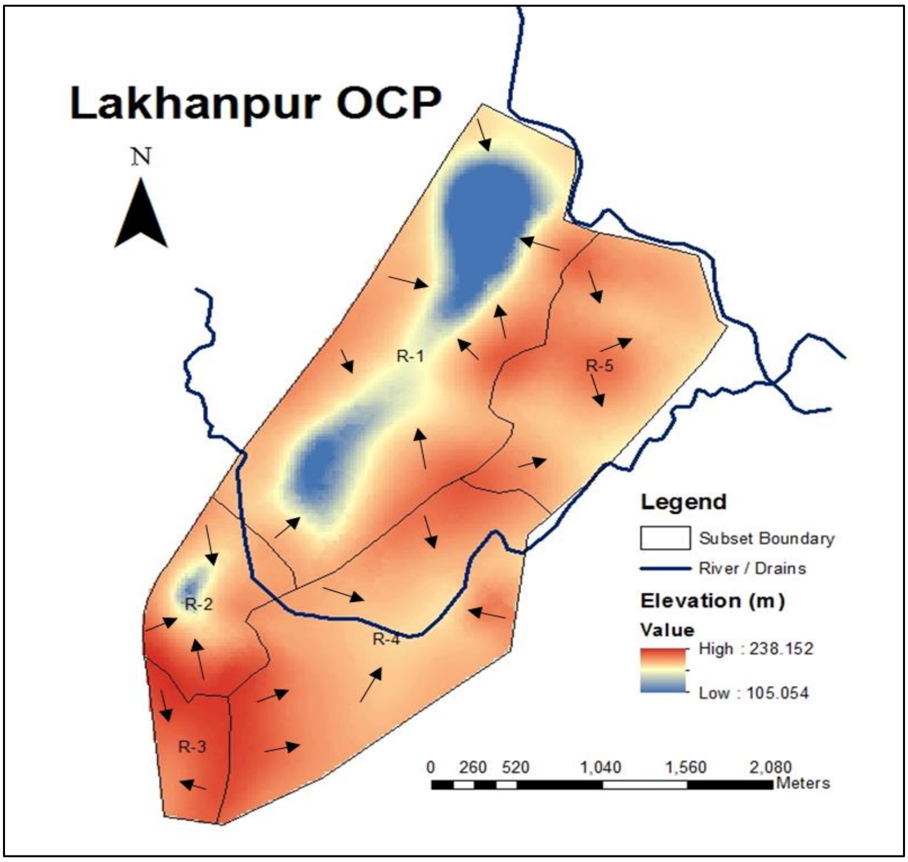

Figure 4.14: Digital Elevation Model of Lakhanpur OCP with arrows denoting the flow direction of water

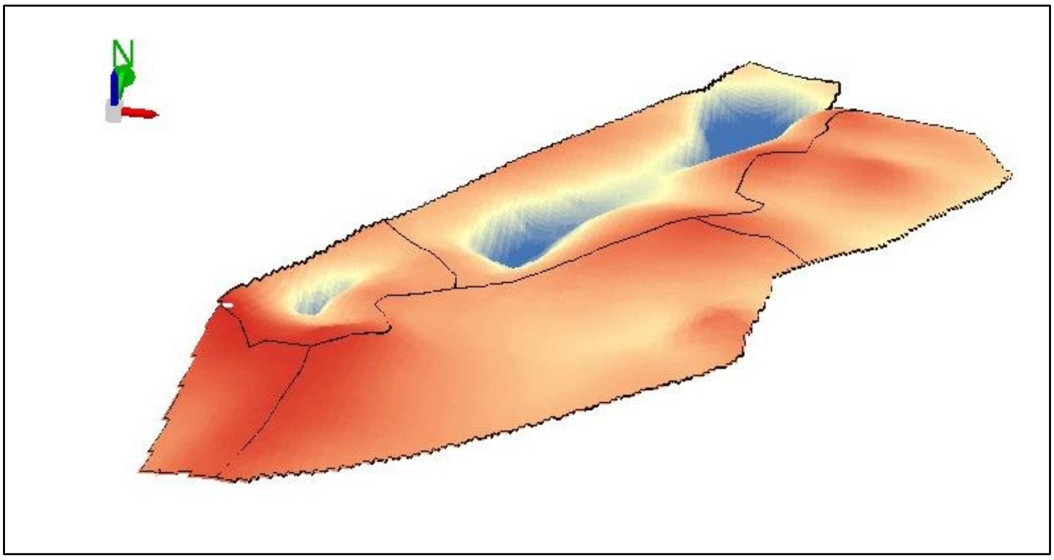

Figure 4.15: 3-D view of DEM of Lakhanpur OCP

Table 4.8: Surface runoff from each region in Lakhanpur OCP

Name	Area (m^2)	Rainfall (m)	Coefficient	Quantity (Lac m^3)	Evaporation Losses (m^3)	Net Quantity (Lakh m^3)	Water Flow Direction
R-4	2314194.94	1.18	0.6	16.38		16.38	Outflow
R-3	393892.28	1.18	0.4	1.85		1.85	Outflow
R-2	768381.4	1.18	0.8	7.25	0.2	7.05	Inflow
R-1	3376084.58	1.18	0.8	31.87	0.6	31.27	Inflow
R-5	1594406.51	1.18	0.6	11.28		11.28	Outflow
Total	8446959.71					67.83	

Monsoon consumption = 4.8 Lakh m^3

Net Quantity of runoff to be stored during monsoon = 63.03 Lakh m^3

Table 4.9: Determination of sump capacity in Lakhanpur OCP

Sump Name	Actual Area (m^2)	Depth (m)	Volume (Lakh m^3)
North	83828.47	24	20.11
Intermediate	70018.62	20	14.00
South	53214.88	16	8.51
Total			**42.62**

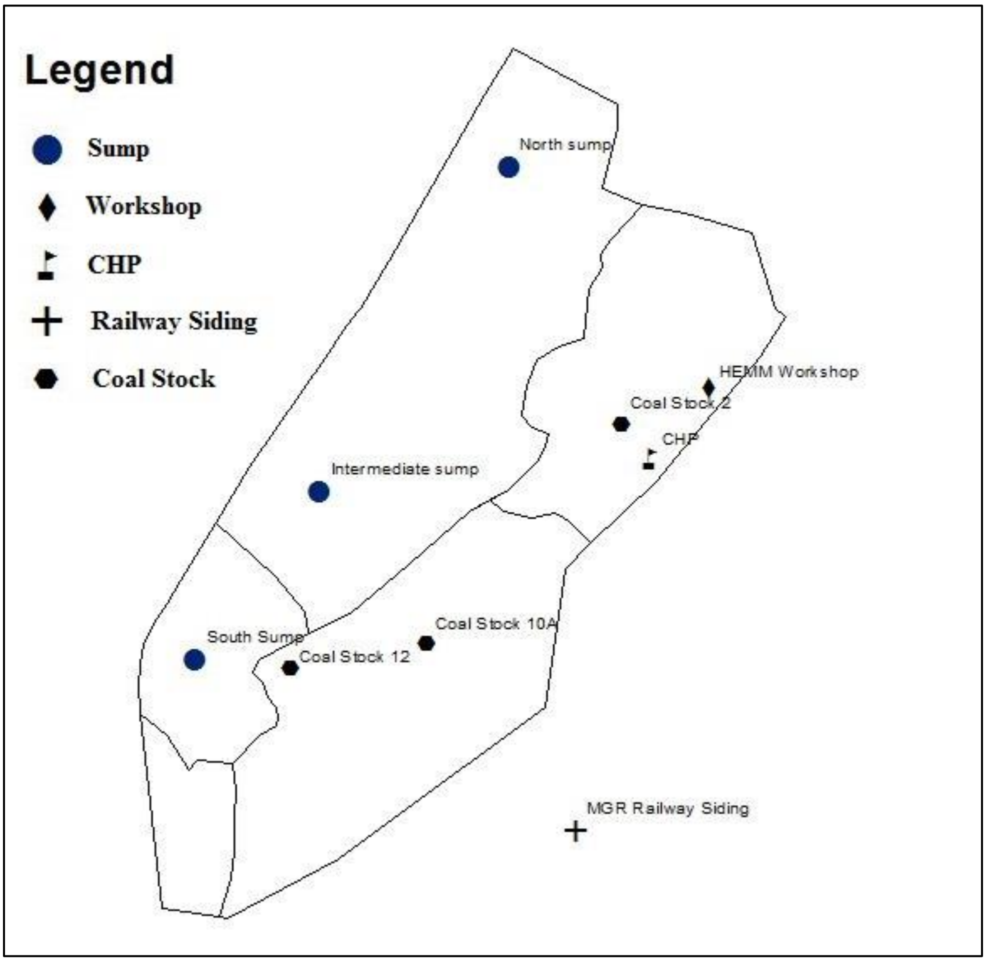

Figure 4.16: Location of important features in Lakhanpur OCP

Recommendations

R3 is in a virgin state; hence runoff from this region may be allowed to take its natural course at the moment.

There is a huge difference between the expected runoff generated in the monsoon months and storage capacity of the mines. Provisions should be made to increase the storage capacity/utilization to accommodate the extra 20.41 Lakh m^3 of runoff generated during the monsoon.

The dumps could be stabilization by proper vegetation. Appropriate scientific study must be carried out to ensure their stability.

Run-off from R5 is flowing into Lilari nallah. There is large scale mining activity in this area with OB dumps, coal stocks, CHP's and transportation roads. The runoff is to be channelized to the mine sumps.

The Pulijhore nallah is flowing through the mine workings is accumulating run-off from coal stocks, OB dumps and backfilled areas of R4 and R5. The entire nallah can be diverted if possible.

Lilari nallah is flowing through Belpahar OCP, Lakhanpur OCP, and Lilari OCP. Hence, to eliminate any risk of contamination of water and inundation of mines, Lilari nallah may be diverted beyond the periphery of these mines.

If provision to accommodate the excess runoff generated during monsoon is not made, then all the runoff can be routed to the North Sump and water from the north sump can be discharged to Lilari nallah. Alternately, an MDTP can be created in the south western section of the mine which will treat the mine water before discharging it into Lilari nallah.

4.7.5 Lilari OCP

Lilari OCP is comparatively smaller than Belpahar and Lakhanpur OCP. The DEM of the mine has been presented in Figure 4.17. Depending upon the flow patterns, the area has been divided into 4 zones (R1 to R4). 3-D view of the DEM has been presented in Figure 4.18. The important surface features in the Lilari OCP have been presented in the Figure 4.19. Calculation of surface runoff and the sump capacity have been presented in Tables 4.10 and 4.11 respectively.

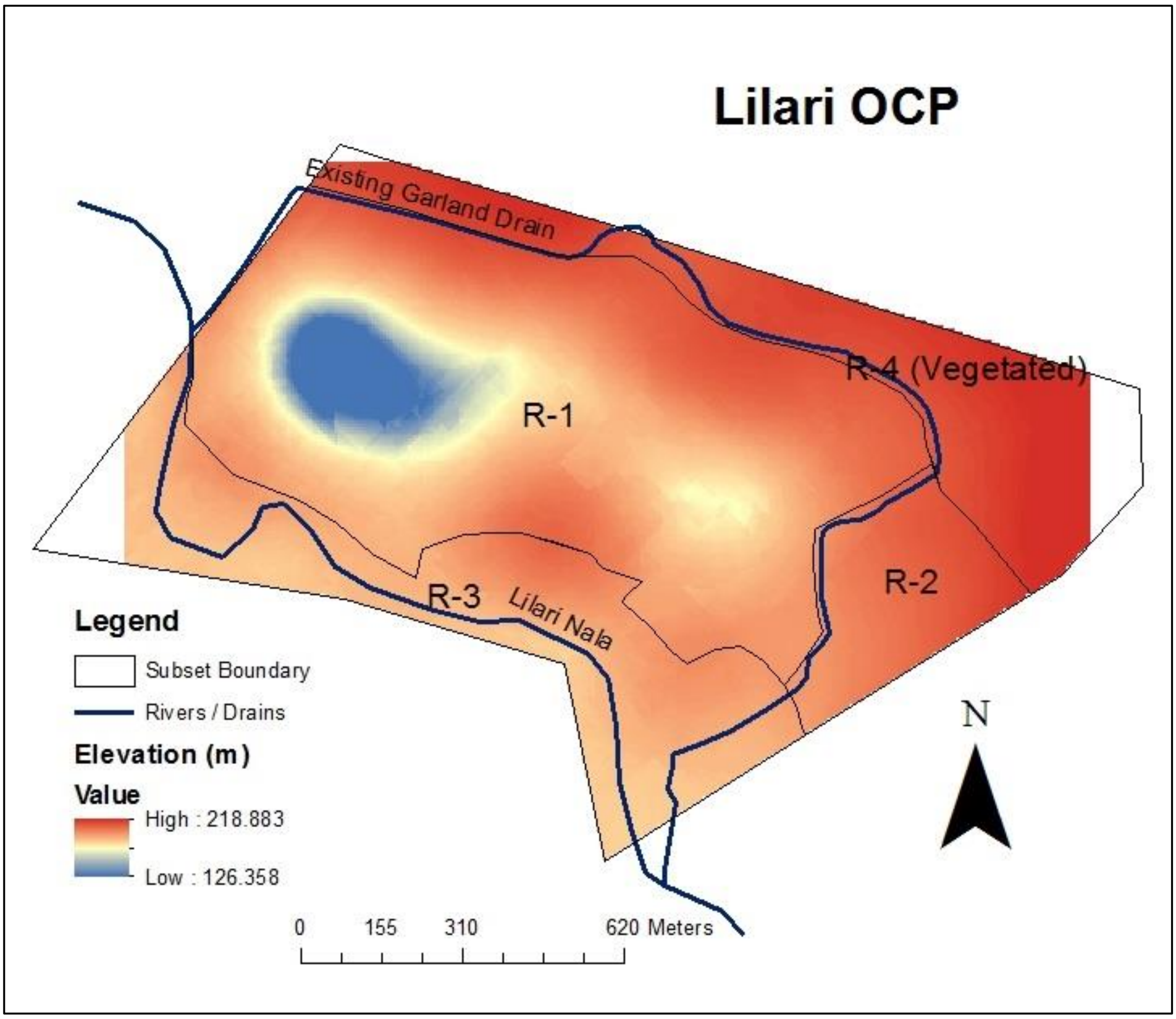

Figure 4.17: Digital Elevation Model of Lilari OCP with arrows denoting the flow direction of water

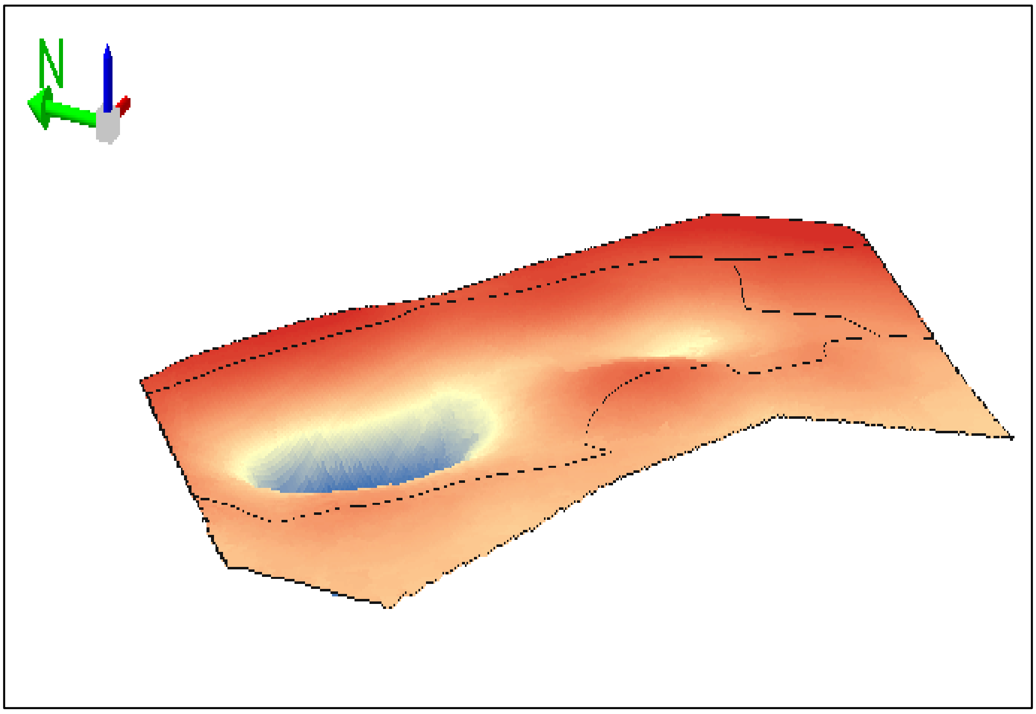

Figure 4.18: 3-D view of DEM of Lilari OCP

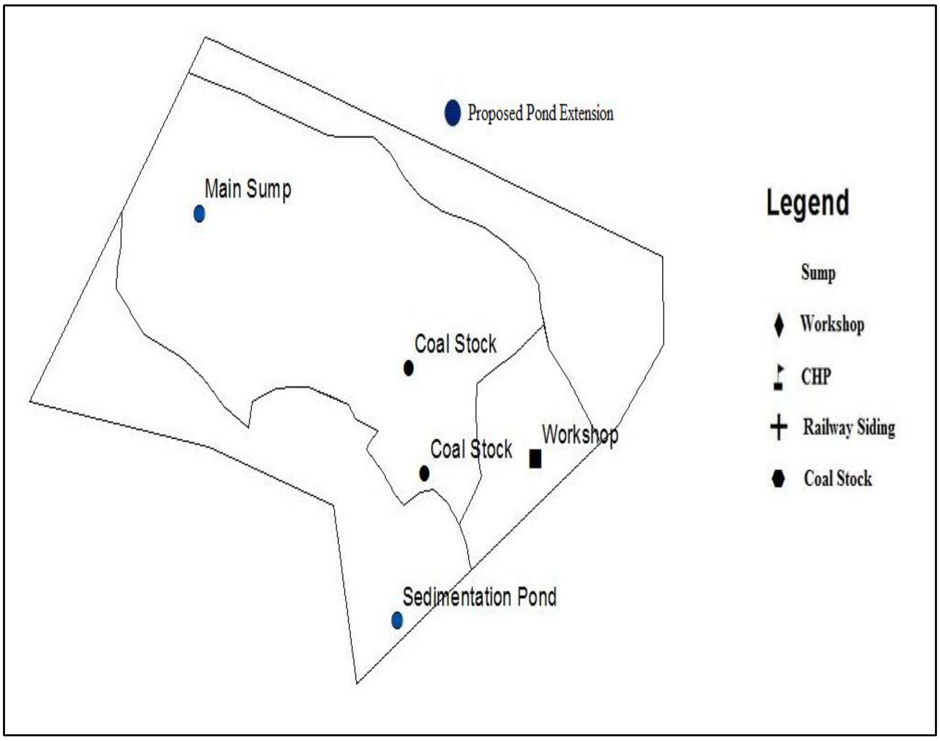

Figure 4.19: Location of important features in Lilari OCP

Table 4.10: Surface runoff from each region in Lilari OCP

Name	Area (m^2)	Rainfall (m)	Coefficient	Quantity (Lac m^3)	Evaporation Losses (m^3)	Net Quantity (Lakh m^3)	Water Flow Direction
R-1	750315.25	1.18	0.8	7.08	0.06	7.02	Inflow
R-3	339460.06	1.18	0.4	1.6		1.6	Outflow
R-4	122743.84	1.18	0.4	0.57		0.57	Outflow
R-2	262167.42	1.18	0.4	1.23		1.23	Outflow
Total	**1474686.57**					**10.42**	

Monsoon consumption = 0.6 Lakh m^3

Net Quantity of runoff to be stored during monsoon = 9.82 Lakh m^3

Table 4.11: Determination of sump capacity in Lilari OCP

Sump Name	Actual Area (m^2)	Depth (m)	Volume (Lakh m^3)
Main Sump	15000	26	3.9
		Total	**3.9**

Recommendation

As majority of R3 region is in its virgin state, the surface runoff can be allowed to take its natural course into Lilari nallah. Surface runoff from the southern slope of the embankment near the boundary of R3 and R1 can be allowed to flow into the Lilari nallah as the area is covered with thick vegetation resembling that natural state.

The overburden dump in R4 is heavily vegetated and has been reclaimed back to its natural state; hence, the runoff generated from this region should also be allowed to take its natural course.

Lilari OCP has an estimated life of 3 more years and the current coal production is 3.0 million tonnes per year. Once the extraction of coal is complete, the mine void can be used a permanent sump to accommodate the total surface runoff.

The runoff from south eastern overburden dump should not be allowed to flow into the Lilari nallah and channeled back to the mining sumps by garland drains

The runoff from R2 should be brought to the mining sumps.

Figure 4.20: Proposed location for extending the existing pond

The existing garland drains channels the run-off in to the Lilari nallah. A sedimentation facility should be provided before the confluence of this westward garland drain and the Lilari nallah. A location has been proposed for extension of existing pond (Figure 4.20).

Run-off from one side of the OB dump on east of R3 is flowing into the nallah directly. Drains should be constructed to prevent this and redirect it towards sedimentation pond.

Provision should be made to increase the sump capacity as there is a huge deficit.

Chapter 5

Water Quality Analysis

Water quality can be defined as the physical, chemical, and biological characteristics of water, usually in respect to its suitability for particular uses (APHA, 2012). In response to environmental concerns and government regulations, water quality assessment is needed for mining industry. In case of the opencast coal mines investigated in this study, the water quality analysis is required to ascertain the contaminants, so that appropriate control measures can be adopted by the respective mines.

Water quality analysis was carried out to ascertain the quality of water within the mines as well as outside the mines. Different water samples were collected from mine sumps, treatment plant inlet and outlet, mine discharges and nearby water bodies in the Ib valley basin for the pre-monsoon and monsoon period in May and August 2015. Coordinate of each sample location was recorded using GPS (GRAMIN 60 CSx). Analysis for Physico-chemical parameters and heavy metal content was carried out following the standard method given in APHA, 2012 and as per the CPCB guidelines. Different sampling points for water quality analysis are shown in Figure 5.1. Sampling location details for both pre-monsoon and monsoon are given in the Tables 5.1 and 5.2. The photographic views of different sampling stations are presented in Figures 5.2 to 5.17.

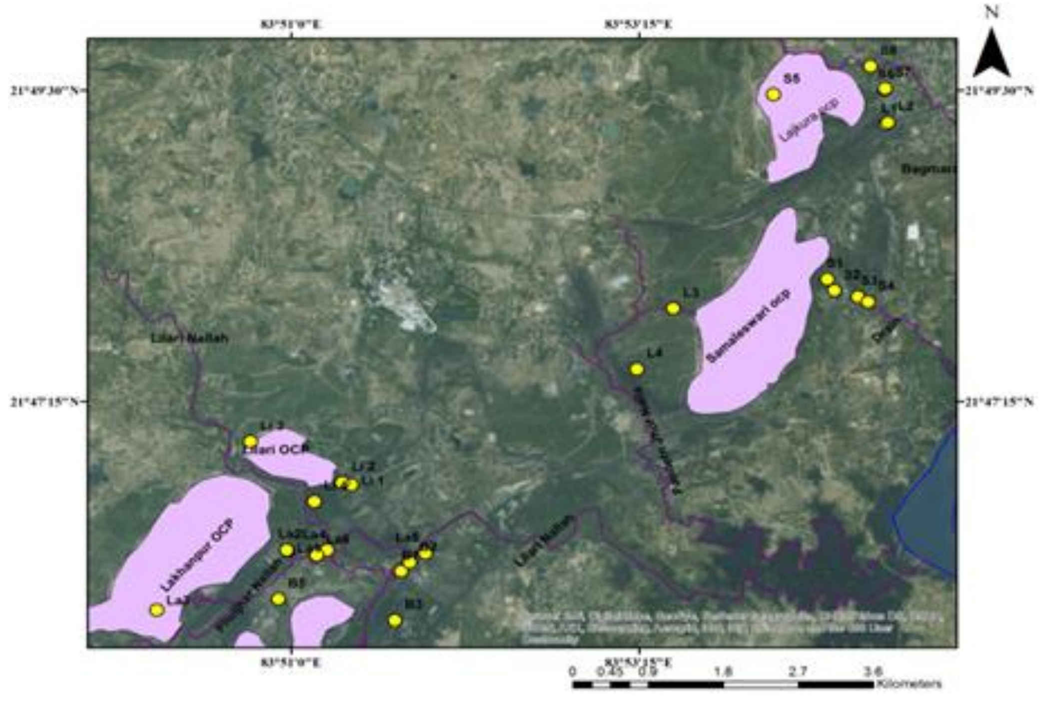

Figure 5.1: Different sampling locations for water quality analysis

Table 5.1: Details of sampling location in pre-monsoon

Sl no	Code	Sample Location
1	**L1**	North sump of mine A
2	**L2**	ETP inlet mine A
3	**L3**	ETP outlet mine A
4	**S1**	Railway siding inletof mine B
5	**S2**	Railway siding outlet of mine B
6	**S3**	Sump of mine B
7	**S4**	MDTP inlet of mine B
8	**S5**	MDTP Outlet of mine B
9	**B1**	Sump of mine C
10	**B2**	MDTP inlet of mine C
11	**B3**	MDTP outlet Of mine C
12	**La1**	Sump of mine D
13	**La2**	ETP inletof mine D
14	**La3**	MDTP outlet Of mine D
15	**Li1**	Sump of mine E
16	**Li2**	Lilari nallah downstream of Belpahar OCP
17	**Li3**	Lilari nallah downstream of Lakhanpur OCP
18	**Li4**	Lilari nallah confluence

Table 5.2: Details of sampling location in monsoon

Sl no	Code	Sample Location
1	**L1**	North Sump of mine A
2	**L2**	ETP inlet mine A
3	**L3**	ETP Outlet mine A
4	**L4**	Bagmara nallah
5	**S1**	Railway siding inlet of mine B
6	**S2**	Railway siding outlet of mine B
7	**S3**	North sump of mine B
8	**S4**	South sump of mine B
9	**S5**	MDTP inlet of mine B
10	**S6**	MDTP outlet of mine B
11	**B1**	MDTP inlet of mine C
12	**B2**	MDTP outlet of mine C
13	**B3**	Sump of mine C
14	**La1**	ETP inletof mine D
15	**La2**	Central sump of mine D
16	**La3**	Lilari nallah upstream
17	**La4**	Lilari nallah downstream
18	**La5**	Pulljhar nallah
19	**Li1**	ETP inlet of mine E
20	**Li2**	ETP outlet of mine E
21	**Li3**	Sump of mine E
22	**Li4**	MDTP Inlet of mine E

Figure 5.2: Lajkura mine sump

Figure 5.3: Lilari mine sump

Figure 5.4: Lilari nallah downstream

Figure 5.5: Lakhanpur ETP inlet

Figure 5.6: Belpahar MDTP plant

Figure 5.7: Pullijhor nallah

Figure 5.8: Samaleswari mine sump

Figure 5.9: Lakhanpur WETP

Figure 5.10: Belpahar WETP

Figure 5.11: Lakhanpur mine sump

Figure 5.12: Field measurement with Horiba G 52 multi water quality monitor

Figure 5.13: Belpahar mine Sump

Figure 5.14: Lilari MDTP inlet

Figure 5.15: Lakhanpur MDTP inlet

Figure 5.16: Lakhanpur mine discharge before mixing with Pullijhor nallah

Figure 5.17: Lilari nallah upstream

5.1 Physical Parameters

The physical properties of the samples such as Temperature, pH, Conductivity, Turbidity, Total dissolved solid (TDS) etc. were measured at the site by using HORIBA U-52multi-parameter water quality analyzer (Figure 5.19). Total Suspended solids (TSS) were measured by gravimetric analysis in the laboratory. The results of physical parameters in pre-monsoon and monsoon of collected water samples are given in the Tables 5.3 and 5.4 respectively.

5.1.1 Multi Parameter Water Quality Meter

HORIBA U-52G multi parameter water quality meter can measure simultaneously up to 11 parameters on the sites such as river, ground water, drainage water etc. This meter has newly designed control unit and sensor technology as shown in Figure 5.18.

Procedure for field measurement

1. The sensors were checked and cleaned with distilled water.
2. The option "SINGLE MEASUREMENT" was selected.
3. The sensor was then dipped into the sample such that no air bubbles remain around the sensor.
4. Once the readings have stabilized, the MEAS key was pressed to acquire result. Three concurrent readings of the results were taken.
5. The measurement was saved by pressing the ENTER key.

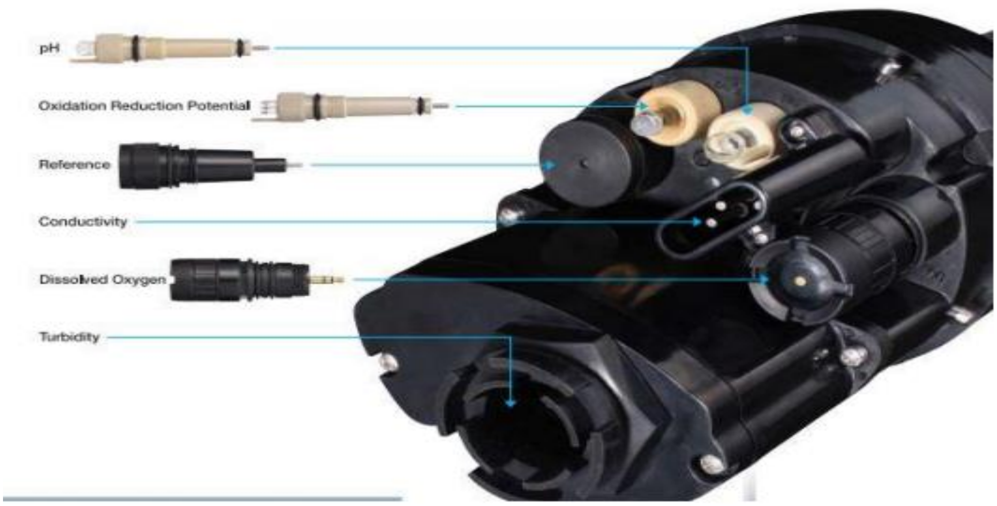

Figure 5.18: Location of sensors in multi-parameter equipment

Figure 5.19: Horiba G 52 Multi Water Quality Monitor

5.1.2 Total Suspended Solids

A measured volume of water was pored through a pre-weighted filter media. Then the filter was kept in oven at 103-105°C for one hour. After removal of water from the filter paper the filter was again weighted for final weight. Calculation of the TSS is given below.

Calculation:

$$TSS = \frac{(\mathrm{Wf} - \mathrm{Wi}) \times 1000}{\mathrm{Vs}}$$

Where,

TSS : Total suspended solids in mg/L

W_f : Final weight of filter paper in (mg)

W_i : Initial weight of filter paper in (mg)

V_s : Volume of sample in (L)

Table 5.3: Analysis of physical parameters in the water samples during pre-monsoon in Ib valley area

Sl. No	Sample code	pH	Temp. (°C)	TDS (mg/L)	Turbidity (NTU)	Cond. (ms/cm)	TSS (mg/L)
1	L1	5.12	31.81	107	9.40	0.513	17
2.	L2	5.56	31.62	186	3.85	0.123	15
3.	L3	6.09	31.58	208	5.97	0.127	12
4.	S1	3.77	31.44	103	2.3	1.43	8
5.	S2	4.55	32.25	111	1.7	1.58	6
6.	S3	5.97	32.33	179	1.8	1.24	16
7.	S4	6.02	32.06	197	5.5	0.349	17
8.	S5	6.07	31.94	115	1.8	0.804	14
9.	B1	6.71	31.33	196	2.0	0.302	19
10.	B2	5.34	31.07	101	8.1	0.127	10
11.	B3	6.01	31.29	117	2.5	0.193	15
12.	La1	7.31	31.14	288	2.3	0.765	23
13.	La2	6.85	31.21	108	9.6	0.155	14
14.	La3	6.83	31.07	101	2.9	0.111	9
15.	Li1	7.64	31.14	266	14.0	0.386	11
16.	Li2	7.15	31.59	219	10.5	0.270	8
17.	Li3	7.22	31.6	210	5.0	0.338	5
18.	Li4	6.56	31.31	174	11.50	0.323	6

Table 5.4: Analysis of physical parameters in the water samples during monsoon in Ib valley area

Sl. No	Sample code	pH	Temp. (^oC)	TDS (mg/L)	Turbidity (NTU)	Cond. (ms/cm)	TSS (mg/L)
1.	L1	3.6	31.43	905	35.3	1.41	316
2.	L2	7.4	31.22	118	111	0.178	621.25
3.	L3	5.9	31.35	63	71.9	0.101	586.25
4.	L4	7.69	31.5	85	159	0.127	542.5
5.	S1	6.08	31.45	310	18.1	0.469	597.5
6.	S2	5.62	31.51	405	8.5	0.703	553.25
7.	S3	6.6	31.35	952	2	1.49	127.5
8.	S4	3.05	31.24	1305	3	2.12	67
9.	S5	7.85	31.35	550	16.5	0.865	102.5
10.	S6	7.6	31.37	311	12.1	0.492	42.5
11.	B1	7.23	31.51	116	324	0.179	310
12.	B2	7.51	31.59	87	527	0.13	256.75
13.	B3	7.52	31.42	343	64.7	0.536	71.75
14.	La1	7.03	31.6	141	205	0.217	589.8
15.	La2	6.05	31.49	525	10	0.819	180.3
16.	La3	6.81	31.51	21	349	0.032	320
17.	La4	6.82	31.17	37	948	0.058	340
18.	La5	6.71	31.52	171	157	0.233	335.5
19.	Li1	6.75	31.6	35	230	0.052	621.5
20.	Li2	7.35	31.42	130	51.7	0.207	349.25
21.	Li3	4.45	31.43	410	14.4	0.46	97.25
22.	LI4	7.03	31.56	106	34.7	0.166	49.75

5.2 Chemical Parameters

Different chemical parameters such as Dissolved oxygen (DO), Biochemical oxygen demand (BOD_3), Chemical oxygen demand (COD), Fluoride, Sulphate, Sodium, Oil and Grease, Chloride content, Boron, were determined in the laboratory. DO was measured by multi water quality meter, Biochemical oxygen demand (BOD_3) was analysed by 3- day BOD test using temperature control BOD incubator and COD was measured by Closed Reflux Titrimetric method. Major anions $SO4^{2-}$ was analysed in turbid metric method by UV/VIS double beam spectrophotometer. Fluoride concentration was measured by orion fluoride electrode using TISAB buffer. Concentration of Na^+ was measured in Flame Photometer. Concentration of chloride was done by titration method. Boron concentration was analyzed in ICP-MS. Principle for analysis of various chemical parameters is as follows. The results of chemical parameters analysed for both pre-monsoon and monsoon have been given in the Tables 5.5 and 5.6.

5.2.1 Determination of Bio-chemical Oxygen Demand (BOD)

BOD of water or polluted water is the amount of oxygen required for the biological decomposition of dissolved organic matter to occur under standard condition at a standardized time and temperature. Usually, the time is taken as 3 days and the temperature is 27°C.

Calculations:

BOD of the sample is calculated as follows:

a) When dilution water is not seeded

$$BOD\ mg/L = \{(D_1 - D_2) \times 100\} / \%\ of\ dilution$$

b) When dilution is seeded

$$BOD\ mg/L = \{(D_1 - D_2) - (B_1 - B_2) \times 100\} / \%\ dilution$$

Where,

D_1 = DO of sample immediately after preparation, mg/L.

D_2 = DO of sample after incubation period, mg/L.

B_1 = DO of blank (seeded dilution water) before incubation, mg/L.

B_2 = DO of blank (seeded dilution water) after incubation, mg/L.

5.2.2 Determination of COD by Open Reflux Titrimetric Method

Principle

The organic matter present in sample gets oxidized completely by potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric acid (H_2SO_4). The sample is refluxed with a known amount of potassium dichromate ($K_2Cr_2O_7$) in the sulphuric acid medium and the excess potassium dichromate ($K_2Cr_2O_7$) is determined by titration against ferrous ammonium sulphate using ferroin indicator. The dichromate consumed by the sample is equivalent to the amount of O_2 required to oxidize the organic matter.

5.2.3 Determination of Fluoride

Principle

When the fluoride electrode is dipped into the sample whose concentration is to be measured, a potential is established by the presence of fluoride ions by any modern pH meter having an expanded millivolt scale. Thus we can find the conc. by measuring the potential difference. The concentration in mg/L is obtained directly from the specific ion meter.

5.2.4 Determination of Sulphate

Principle

Sulfate ion (SO_4^{-2}) is precipitated in acetic medium with barium chloride ($BaCl_2$) so as to form barium sulphate ($BaSO_4$) crystals of uniform size. Light absorbance of the $BaSO_4$ suspension is measured by a spectrophotometer at 420nm and SO_4^{-2}concentration is determined by a composition of the reading with standard curve. The turbid metric method for determination of sulfate concentration is based on the fact that light is scattered by particulate matter in aqueous solution. When barium and sulfate react in water, they make the solution turbid, which means the concentration of the Sulfate can be measured by using a spectrophotometer (Figure 5.20). The equation for the reaction of barium and sulfate is shown below:

$$SO_4^{2-}(aq) + Ba_2^{+}(aq) \longrightarrow BaSO_4(s)$$

Figure 5.20: Photographic view of Double Beam Spectrophotometer (Model no 2357 EI)

5.2.5 Determination of Sodium by Flame photometry

Principle

Sodium (Na) is the major extracellular cation and it plays a role in body fluid distribution. When a solution containing cations of sodium and potassium is sprayed into flame, the solvent evaporates and ions are converted into atomic state. In the heat of the flame, small fraction of the atoms is excited. Relaxation of the excited atoms to the lower energy level is accompanied by emission of light (photons) with characteristic wavelength (Na: 589 nm). Intensity of the emitted light depends on the concentration of particular atoms in flame.

The standard solution is aspirated through the Atomiser unit. The standard solution, air, and fuel are mixed inside the mixing chamber to convert into fine particles of mist; then it is sprayed into the flame. The concentration of the elements reflected through the change in colour of the flame. The radiation flame passes through the sensing unit and the narrow band of interference filter which allows the specific characterized radiation to the photo detector. It analyses the radiation and displays the output data on the LCD screen. The photographic view of flame photometry is shown in the Figure 5.21.

Figure 5.21: Photographic view of the Flame Photometer Set up

5.2.6 Determination of Oil and Grease

Concentration of Oil and Grease was determined by Partition Gravimetric Method.

Principle

Extraction of dissolved or emulsified oil and grease is carried out by intimate association with an extracting solvent. Since unsaturated fats and fatty acids are readily oxidisable, precaution regarding temperature and solvent vapour displacement are involved to reduce this effect. This method is useful for handling emulsion that is formed due to organic solvents being shaken with some samples is difficult to breakdown. Solvent recovery can decrease vapor emissions to the atmosphere.

Calculation

Oil and grease in mg/L= W_r/Vs

Where

W_r = total weight of flask and residue- tare weight of flask in mg

Vs =Initial sample volume

5.2.7 Determination of Chloride

Principle

Chloride is a mobile ion and commonly occurs as soluble salts such as NaCl, $CaCl_2$, and $MgCl_2$. Argentometric titration method is used to determine the Cl^- content in water samples. This method is based on the formation of slightly soluble white precipitate of AgCl due to the addition of $AgNO_3$ solution in presence of potassium chromate indicator. $AgNO_3$ reacts with chloride to form AgCl. At the end point, when all the chlorides get precipitated, free silver ions react with chromate to form silver chromate ($AgCr_2O_4$) of reddish brown color.

Table 5.5: Analysis of chemical parameters in the water samples during pre-monsoon in Ib valley area

Sl. No	Sample code	DO (mg/L)	BOD_3 (mg/L)	COD (mg/L)	Fluoride (mg/L)	Sulphate(mg/L)	Sodium(mg/L)	Oil and grease (mg/L)	Chloride (mg/L)	Boron (mg/L)
1	L1	8.51	2.1	37.8	0.1	178	11.87	1.87	26	0.011
2.	L2	8.29	1.8	35.1	0.3	112	10.59	2.48	24	BDL
3.	L3	8.26	1.5	32.4	0.3	108	10.37	2.23	20	BDL
4.	S1	10.90	3.43	33.7	0.1	77	37.5	1.3	33.7	0.024
5.	S2	8.84	2.56	29.2	0.1	73	29.57	1	28.4	0.019
6.	S3	9.14	1.88	31.4	0.3	143	17.3	2.3	21.6	BDL
7.	S4	8.81	2.98	27.8	0.3	108	17	0.9	23.6	BDL
8.	S5	8.57	1.99	27.4	0.3	103	13	0.6	21.4	BDL
9.	B1	8.24	1.6	28.3	0.2	102	26.5	0.91	19	BDL
10.	B2	9.84	2.7	33.2	0.2	75	21.54	1.9	36	BDL
11.	B3	9.54	2.4	31.7	0.2	67	21.38	1.34	30	BDL
12.	La1	8.52	3.4	32.7	0.2	102	10.3	2.81	16	BDL
13.	La2	8.09	0.9	29.7	0.1	53	5.8	1.27	19	BDL
14.	La3	8.47	1.1	31.4	0.3	58	5	1.03	22	BDL
15.	Li1	8.50	2.89	21.4	0.1	64.6	5.1	2.21	21	BDL
16.	Li2	8.69	1.9	38.9	0.1	11.2	8.8	0.098	53	BDL
17.	Li3	9.15	1.88	35.2	0.1	10.8	8.9	0.77	62	BDL
18.	Li4	9.04	1.97	35.6	0.1	11.1	8.7	1.13	60	BDL

Table 5.6: Analysis of chemical parameters in the water samples during monsoon in Ib valley area

Sl. No	Sample code	DO (mg/L)	BOD_3 (mg/L)	COD (mg/L)	Fluoride (mg/L)	Sulphate (mg/L)	Sodium (mg/L)	Oil and grease (mg/L)	Chloride (mg/L)	Boron (mg/L)
1.	L1	5.46	3.44	32.4	0.01	262.6	14.93	0.93	22.9	0.02
2.	L2	4.81	2.9	38.1	0.6	64.1	12.21	1.77	21.3	0.019
3.	L3	5.94	3.55	35.7	0.4	59.2	11.56	1.54	20.59	0.012
4.	L4	5.85	3.36	22.43	0.5	81.069	14.79	0.33	22.72	BDL
5.	S1	6.19	3.88	33.2	0.6	50.6	16.41	2.55	29.11	0.036
6.	S2	5.76	3.63	29.8	0.3	50.2	15.43	2.4	25.56	0.024
7.	S3	7.06	2.14	41.2	0.02	322.2	17.97	2.3	24.14	BDL
8.	S4	6.59	3.08	39.7	0.007	493.4	26.45	2.8	28	0.009
9.	S5	5.2	2.82	32	0.8	244.8	14.89	2.9	24.19	BDL
10.	S6	6.14	3.12	31.6	0.4	223.4	14.01	2.7	22.72	BDL
11.	B1	5.2	3.22	35.66	0.3	164.1	28.77	2.93	21.3	BDL
12.	B2	5.47	2.49	32.44	0.4	119.7	41.01	2.77	22.01	BDL
13.	B3	4.96	2.95	34.69	0.6	174.1	23.32	1.23	26.27	BDL
14.	La1	4.61	2.68	29.8	0.3	145.6	9.11	1.31	17.04	BDL
15.	La2	5.26	1.34	22.1	0.2	123.8	12.32	2.44	17.01	BDL
16.	La3	5.61	1.66	20.4	0.2	132.5	18.12	0.18	17.04	BDL
17.	La4	4.98	3.39	20.8	0.2	244	16.11	0.77	15.62	BDL
18.	La5	5.31	1.38	28.3	0.3	145.6	17.14	1.3	18.46	BDL
19.	Li1	5.57	3.22	19.9	0.3	122.6	6.13	0.97	14.2	BDL
20.	Li2	5.41	3.1	25.44	0.5	82.7	6.96	0.83	14.91	BDL
21.	Li3	5.09	1.74	21.3	0.008	249.7	11.67	1.05	13.49	BDL
22.	LI4	5.59	3.29	19.8	0.3	143.6	11.43	1.13	27.69	BDL

5.3 Heavy Metal Analysis

For the determination of concentration of Heavy metals viz. Zinc, Cadmium, Copper, Lead, Nickel, Selenium, Arsenic, Chromium and Mercury, Inductively Coupled Plasma Mass Spectrometry (ICP MS) was used. At first, the sample was filtered using Millipore 0.45µ (micron) membrane filter and HNO_3 acid was added to ensure the pH was around 2 followed by analysis in ICP-MS. The results of heavy metal analysis for both pre-monsoon and monsoon is shown in the Tables 5.7 and 5.8 respectively.

5.3.1 Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is an analytical technique used for elemental determination. The technique was commercially introduced in 1983 and has gained general acceptance in many types of laboratories. Geochemical analysis labs were early adopters of ICP-MS technology because of its superior detection capabilities, particularly for the rare-earth elements (REEs).

ICP-MS Working Principle:

The plasma is formed from argon gas flowing normally through a Fassel quartz torch made of three concentric tubes. Argon gas is introduced by the most outer tube which flows at a relatively high flow rate around 20 L/min so as to avoid the torch from melting and enable it forms characteristic profile of the plasma. A supplementary argon gas flow up to 1.5 L/min is introduced into the middle conduit to stabilize the plasma. It may be attuned to divert the plasma base, so as to influence the depth of sampling-distance between plasma and the sampler cone. The injector which is the most inner tubes is used to introduce the sample aerosol into the plasma at the flow rate of argon gas, typically up to 1.5 L/min. The torch is then positioned in an induction coil which is made of copper and coated with argon liquid, and connected to a RF (RADIO frequency) generator. The oscillation of the RF generates a magnetic field at the top of the torch. Ignition of plasma is done by means high voltage sparks produced by argon gas. Electrons from ignition are accelerated in the magnetic field and strike with neutral argon atom. These collisions generate further electrons and produce a chain reaction. The plasma formed comprises of argon atoms, argon ions (positively charged) and electrons, which signifies quasi-neutral state. Moreover, the collision of argon atoms generates high temperature of plasma in the range of 6000K to 10000K, depending on the region. Meanwhile, the gas flows within the number of regions of the torch are dissimilar and plasma formed is characteristically annular *(Kovacs et al., 2010; Montaser 1998).* ICP-MS image and schematic diagrams of ICPMS is shown in Figure 5.22 and 5.23 respectively.

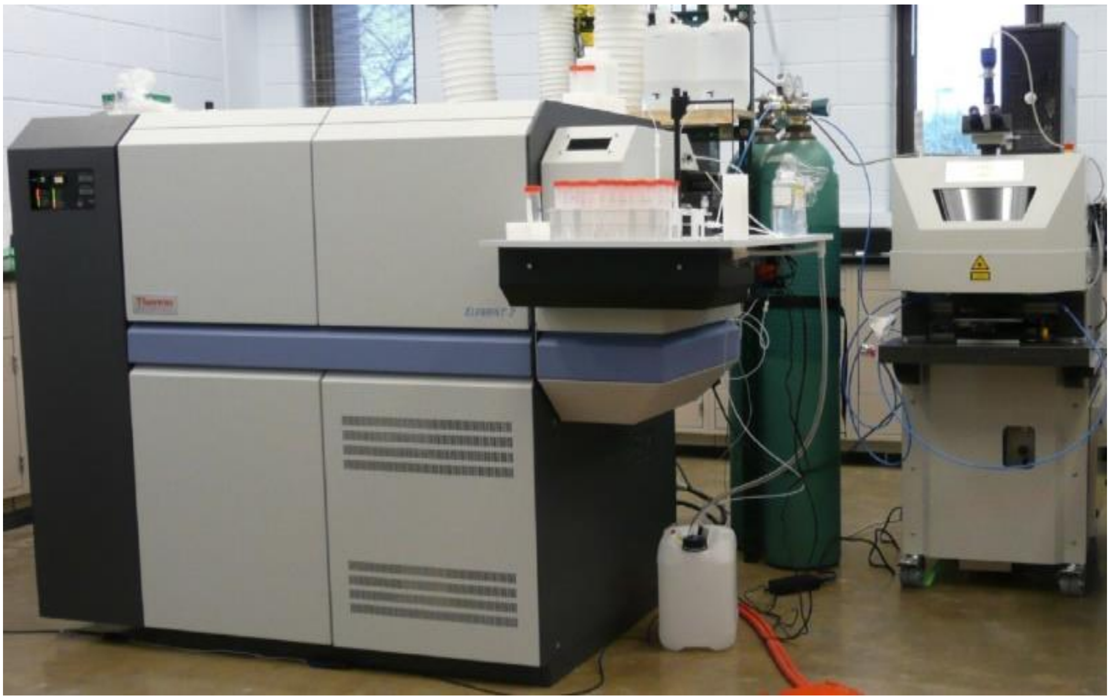

Figure 5.22: Photographic view of inductively coupled plasma mass spectrometry (ICP-MS)

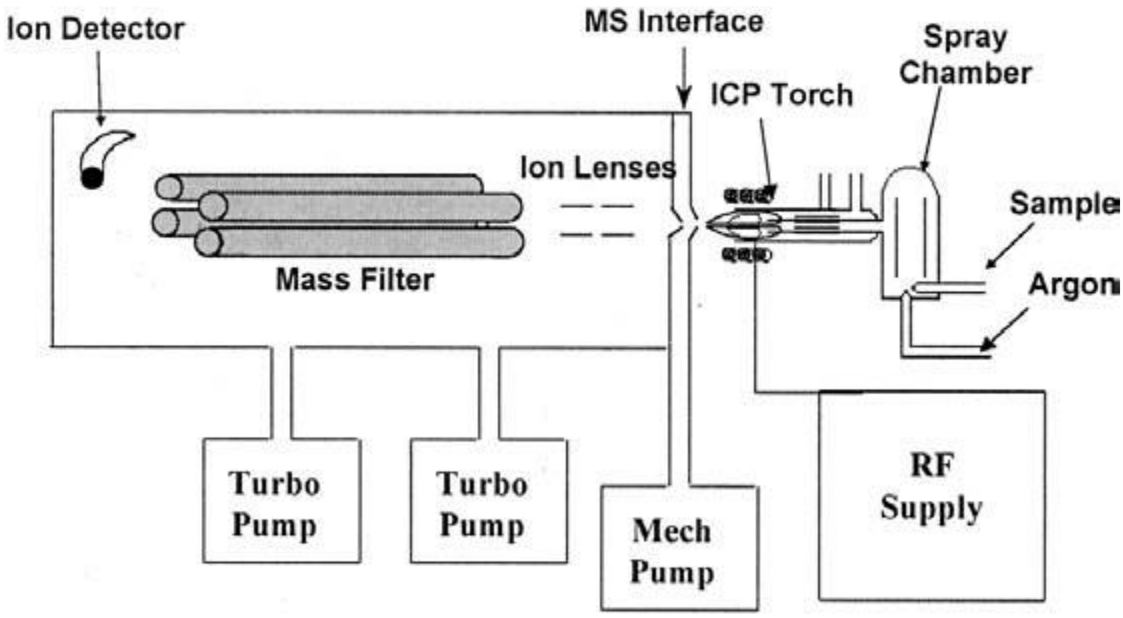

Figure 5.23: Schematic diagram of ICP MS

Table 5.7: Analysis of heavy metal in the water samples during pre-monsoon in Ib valley area

Sl. No	Sample code	Zinc (mg/L)	Copper (mg/L)	Cadmium (mg/L)	Lead (mg/L)	Selenium (mg/L)	Arsenic (mg/L)	Mercury (mg/L)	Chromium (mg/L)	Nickel (mg/L)
1	L1	0.227	BDL	0.01	BDL	0.027	0.013	BDL	0.011	0.27
2.	L2	0.146	BDL	0.006	BDL	0.07	BDL	BDL	0.003	0.006
3.	L3	0.129	BDL	0.007	BDL	0.053	BDL	BDL	BDL	0.003
4.	S1	0.32	0.018	0.004	BDL	0.048	BDL	BDL	BDL	0.346
5.	S2	0.29	0.003	0.005	BDL	0.051	BDL	BDL	BDL	0.325
6.	S3	0.055	BDL	0.004	BDL	0.06	BDL	BDL	BDL	0.218
7.	S4	BDL	BDL	0.004	BDL	0.036	BDL	BDL	BDL	0.104
8.	S5	BDL	BDL	0.003	BDL	0.047	BDL	BDL	BDL	0.093
9.	B1	BDL	BDL	0.001	BDL	0.074	0.001	BDL	BDL	0.015
10.	B2	BDL	BDL	0.006	BDL	0.1	BDL	BDL	BDL	BDL
11.	B3	BDL	BDL	0.004	BDL	0.069	BDL	BDL	BDL	0.007
12.	La1	BDL	BDL	0.006	BDL	0.047	0.003	BDL	BDL	0.025
13.	La2	BDL	BDL	0.007	BDL	0.04	BDL	BDL	BDL	0.003
14.	La3	BDL	BDL	0.004	BDL	0.057	BDL	BDL	BDL	BDL
15.	Li1	BDL	BDL	0.004	BDL	0.04	0.002	BDL	BDL	0.003
16.	Li2	BDL	BDL	0.006	BDL	0.045	BDL	BDL	BDL	0.001
17.	Li3	BDL	BDL	0.005	BDL	0.042	BDL	BDL	BDL	0.007
18.	Li4	BDL	BDL	0.004	BDL	0.048	BDL	BDL	BDL	BDL

Table 5.8: Analysis of heavy metal in the water samples during monsoon in Ib valley area

Sl. No.	Sample code	Zinc (mg/L)	Copper (mg/L)	Cadmium (mg/L)	Lead (mg/L)	Selenium (mg/L)	Arsenic (mg/L)	Mercury (mg/L)	Chromium (mg/L)	Nickel (mg/L)
1.	L1	0.53	0.024	0.009	BDL	0.58	0.008	BDL	BDL	0.71
2.	L2	0.268	BDL	0.006	BDL	0.028	BDL	BDL	0.032	0.009
3.	L3	0.14	BDL	0.003	BDL	0.015	BDL	BDL	0.011	0.002
4.	L4	0.032	BDL	0.001	BDL	0.011	BDL	BDL	0.031	BDL
5.	S1	0.357	0.021	0.005	BDL	0.044	BDL	BDL	BDL	0.366
6.	S2	0.31	0.014	0.004	BDL	0.055	BDL	BDL	BDL	0.34
7.	S3	0.062	BDL	0.007	BDL	0.068	BDL	BDL	BDL	0.274
8.	S4	0.84	1.21	0.008	0.013	0.074	0.007	BDL	BDL	0.65
9.	S5	BDL	BDL	0.004	BDL	0.047	BDL	BDL	BDL	0.104
10.	S6	BDL	BDL	0.002	BDL	0.036	BDL	BDL	BDL	0.09
11.	B1	BDL	BDL	0.001	BDL	0.067	BDL	BDL	BDL	BDL
12.	B2	BDL	BDL	BDL	BDL	0.053	BDL	BDL	BDL	BDL
13.	B3	BDL	0.021	0.002	BDL	0.071	0.002	BDL	BDL	0.015
14.	La1	BDL	BDL	0.002	BDL	0.036	BDL	BDL	0.008	0.005
15.	La2	0.008	BDL	0.004	BDL	0.051	0.005	BDL	BDL	0.021
16.	La3	0.025	BDL	0.001	BDL	0.011	BDL	BDL	BDL	0.005
17.	La4	0.023	BDL	BDL	BDL	0.017	BDL	BDL	BDL	0.008
18.	La5	0.018	BDL	BDL	BDL	0.016	BDL	BDL	BDL	BDL
19.	Li1	0.005	BDL	0.004	BDL	0.043	BDL	BDL	BDL	0.004
20.	Li2	BDL	BDL	0.003	BDL	0.036	BDL	BDL	BDL	BDL
21.	Li3	0.44	0.008	0.005	BDL	0.043	0.005	BDL	BDL	0.22
22.	LI4	0.017	0.004	0.003	BDL	0.032	BDL	BDL	BDL	0.03

Chapter 6

Discussion and Conclusions

This chapter describes the discussions on the rain fall data analysis, mine wise surface runoff and sump capacity analysis and analysis of physico-chemical parameters in pre-monsoon and monsoon season in Ib valley area. Some general recommendations has been suggested for the mine managements. It also provides the summary of the research investigation and outlines the specific conclusion drawn from the research findings. Further, it states some potential areas of application of this study and direction for future research.

6.1 Analysis of Rainfall Data

Analysis of the rainfall data for any specific study area is an essential requirement in order to have a realistic assessment of the runoff and its management. In order to analyse, the rainfall data of 16 consecutive years from 2000 to 2015 was collected. The month wise total average rainfall data from 2000-2015 is shown in Figure 6.1 and year wise total average rainfall in monsoon season (June to September) has been shown in Figure 6.2.

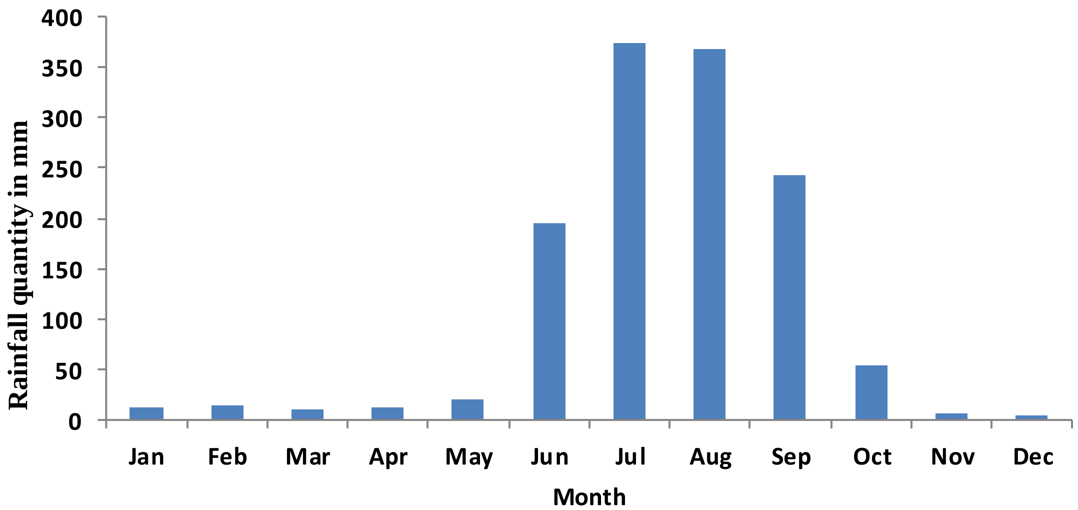

Figure 6.1: Month wise total average rainfall data from 2000-2015

Generally, it is seen that heavy rainfall occurs in July and August as compared to June and September as represented in the Figure 6.1. Rests of the months have very less amount of rainfall. The maximum rainfall that occurred in this area during monsoon was 1613 mm in 2012.

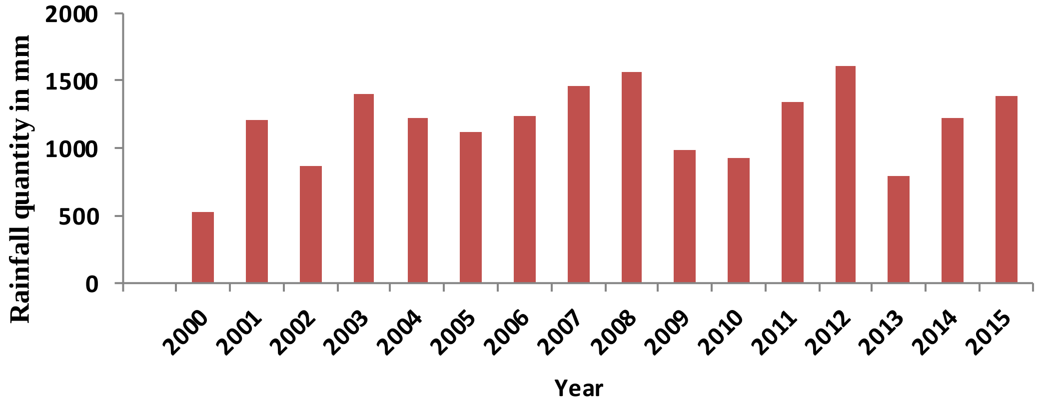

Figure 6.2: Year wise total average rainfall in monsoon season from 2000-2015

6.2 Analysis of Surface Runoff and Sump Capacity

A comparative plot of the estimated surface runoff quantity during monsoon and sump capacity for all five opencast coal mines in the Ib Valley basin is shown in Figure 6.3.

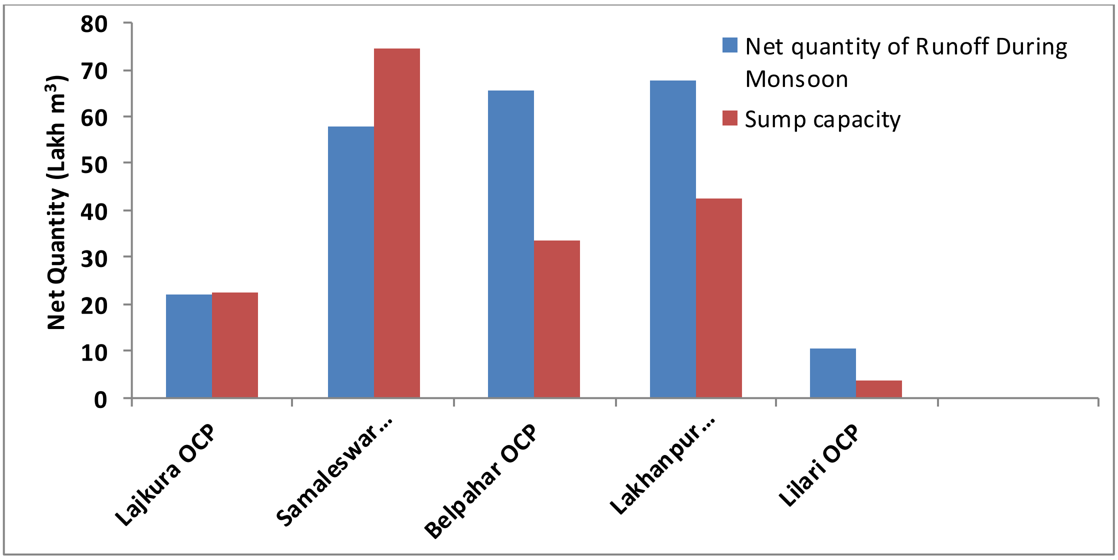

Figure: 6.3 Mines wise quantity of runoff and sump capacity

It may be seen in Figure 6.3 that Lakura and Samaleswari mines have adequate sump capacity to accommodate the surface runoff likely to be generated during the monsoon period. But there is a huge difference between the expected runoff generated in the monsoon period and the storage capacity in Belpahar, Lakhanpur, and Lilari opencast coal mines. This indicates that the mine management of these three mines should take immediate steps to create an adequate storage space within the mine premises to store the estimated additional runoff of extra 29.62 Lakh m^3 in Belpahar, 20.41 Lakh m^3 in Lakhanpur and 5.92 Lakh m^3 in Lilari OCP in monsoon. However, if it is not possible to create the storage space or sumps, then provision for sedimentation ponds or MDTPs of adequate dimension should be constructed as suggested in recommendation in section 4.7.3, 4.7.4 and 4.7.5. Thus, the runoff could be treated before releasing it to the nearby water bodies.

6.3 Water Quality Analysis

The experimental results of all the water samples collected from Ib valley coalfield are compared with the effluent water quality standards prescribed under Environmental Protection Rules, 1986 as shown in the Table 6.1

Table 6.1: Effluent water quality standards under Environmental Protection Rules, 1986

Sl. No.	Parameters	Standards Prescribed under Env. Prot. Rules, 1986	
		Into inland surface water	On land for irrigation
1.	pH	5.5-9.0	5.5-9.0
2.	Temperature (^oC)	Shall not exceed 40^0C in any section of the stream within 15m downstream from the effluent point	
3.	TDS (mg/L)	2100	2100
4.	TSS (mg/L)	100	200
5.	BOD_3 (mg/L)	30	10
6.	Chloride (mg/L)	1000	600
7.	COD (mg/L)	250	-
8.	Fluoride (mg/L)	2.0	-
9.	Sulphate (mg/L)	1000	-
10.	Zinc (mg/L)	5.0	-
11.	Copper (mg/L)	3.0	-
12.	Cadmium (mg/L)	1.0	-
13.	Lead (mg/L)	0.1	-
14.	Selenium (mg/L)	0.05	-
15.	Arsenic (mg/L)	0.2	0.2
16.	Mercury (mg/L)	0.01	-
17.	Chromium (mg/L)	2.0	-
18.	Nickel (mg/L)	3.0	-
19.	Oil and grease (mg/L)	10	10
20.	Sodium (mg/L)		
21.	Boron (mg/L)	2.0	2.0

Physical Parameters

Significant physical parameters were analysed for collected water sample in the Ib valley area. These includes Temperature, pH, Conductivity, Turbidity, TDS and TSS.

The pH of analysed water samples varied from 3.77 to 7.64 in pre- monsoon and 3.05 to 7.85 in monsoon season. The pH of sample S1 and S2 in pre-monsoon is acidic in nature with corresponding value 3.77 and 4.55. Sample namely L1, S4 and Li3 are found to be highly acidic with corresponding values 3.6, 3.05, and 4.45 in monsoon.

Temperature values at all sampling locations ranges from minimum 31.07^0C at La 3 and maximum 32.33^0C at S3 in pre- monsoon. In monsoon maximum of 31.17 ^{0}C at La 4 and minimum of 31.59 ^{0}C at B2 were recorded.

A large variation in the concentrations of TDS was observed in different locations varied with minimum value of 101 mg/L at La3 and maximum value of 288 mg/L at La1 in pre-monsoon and minimum of 21 mg/L at La 3 and maximum of 1305 mg/L at S4 in monsoon.

The conductivity of all water samples ranged from 0.111 to 1.58 ms/cm at La3 and S2 in pre-monsoon and 0.032 to 2.12 at La3 and S4 in monsoon.

There is a large variation in TSS in comparision with pre-monsoon and monsoon water quality. It varied from 5 to 23 mg/L at Li3 and La1 in pre-monsoon and 42.5 to 621.5 mg/L at S6 and Li1 in monsoon.

The turbidity value of all sampling locations ranged from minimum 1.7 NTU at S2 and maximum 14.0 NTU at Li1 in pre-monsoon season. In monsoon minimum 2 NTU at S3 and 948 NTU at La 4 were found.

Chemical Parameters

The Dissolved Oxygen (DO) of the collected sample varied from minimum 8.09 mg/L at La 2 to maximum10.90 mg/L at S1 in pre monsoon and minimum 4.61 mg/L at La1 to maximum 7.06 mg/L at S3 in monsoon period. The concentration of Biochemical Oxygen Demand (BOD_3) varied from 0.9 to 3.4 mg/L in pre-monsoon and 1.34 to 3.88 mg/L in monsoon season. The concentration of Chemical Oxygen Demand (COD) varied from 21.4 to 38.9 mg/L in pre-monsoon and 19.9 to 41.2 mg/L in monsoon season.

Fluoride concentration of all the water samples varied from 0.1 to 0.3 mg/L in pre-monsoon and 0.007 to 0.6 mg/L in monsoon respectively.

Sulphate concentration of all the water samples varied from 11.1 to 178 mg/L in pre-monsoon and 50.2 to 493.4 mg/L monsoon season.

Sodium concentration of all the water samples ranged from 5 mg/L to 37.5 mg/L in pre-monsoon and 6.13 to 41.01 mg/L in monsoon season.

The concentration chloride of all the water samples mg/L varied from 14.2 mg/L to 29.11 mg/L in pre-monsoon and 19.0 mg/L to 62.0 mg/L in monsoon season.

The concentration of Boron in most of the water sample was found Below Detection Limit (BDL).

Heavy Metals

The concentrations of Zinc, Cadmium, Copper, Lead, Arsenic, Chromium and Mercury were found within the permissible limit in all of the water samples.

Concentration of Selenium is above the permissible limit in the sample L2, L3, S2, S3, B1, B3, and La3 in pre-monsoon and L1, S2, S3, S4, B1, B2, B3, and La2 in monsoon season. Furthermore, the concentration of L1 is way above the permissible limit. It has been observed in the past that chronic exposure to selenium compounds is associated with several adverse health effects in humans (*World Health Organization 2011*). An early toxic effect of selenium is on endocrine function and other adverse effects are natural killer of cells activity, hepatotoxicity and gastrointestinal disturbances, dermatologic effects such as nail and hair loss, and dermatitis, occurs after exposure to high levels of environmental selenium. *(U. S. Environmental Protection Agency, 2000).* High concentrations of selenium absorption may cause reproductive failure and birth defects in animals. Selenium poisoning causes aquatic animal like fishes to develop symptoms like elevated lymphocytes, reduced hematocrit, and hemoglobin (anemia), corneal cataracts, reproductive failure, teratogenic deformities of the spine, head and mouth *(Lemly, A. D. 2002).*

In all the water samples, concentration of nickel are within the permissible limit as compared to effluent standards prescribed under Environment Protection Rules, but a high amount of nickel has been observed in some of the water samples.

Concentration Contour Maps

Geographical information system (GIS) is an effectivetechnique for the zone mapping and risk assessment on environmental problems. The GIS based analysis of the concentration contour map of the study area was done by using by using the Q GIS 2.14.1.software with the inverse distance weighted (IDW) interpolation technique. Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable.

Concentration contour map of pH, TDS, TSS, BOD_3,Sulphate, Flouride, Chloride, and COD in pre-monsoon and monsoon season are shown in the Figure 6.4 to 6.21.

The pH in pre-monsoon varies from 3.77 to 7.63 and 3.05 to 7.84 in monsoon. These variations are shown in the Figures 6.4 and 6.5 respectively.

The variation of TDS lies from 101mg/L to 288 mg/L in pre- monsoon and 21 mg/L to 1305 mg/L in monsoon.

The variation of concentration of other parameters are shown in the figures below.

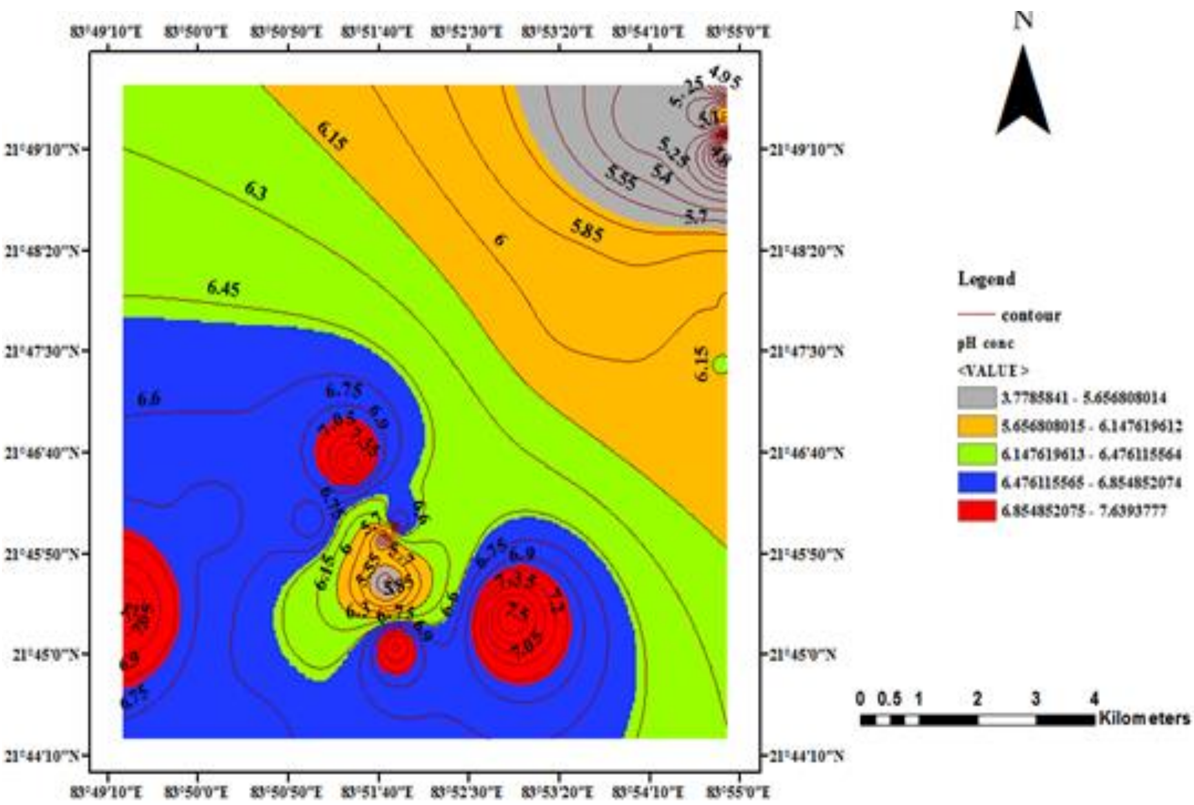

Figure 6.4: Pre-monsoon concentration contour map of pH in Ib valley area

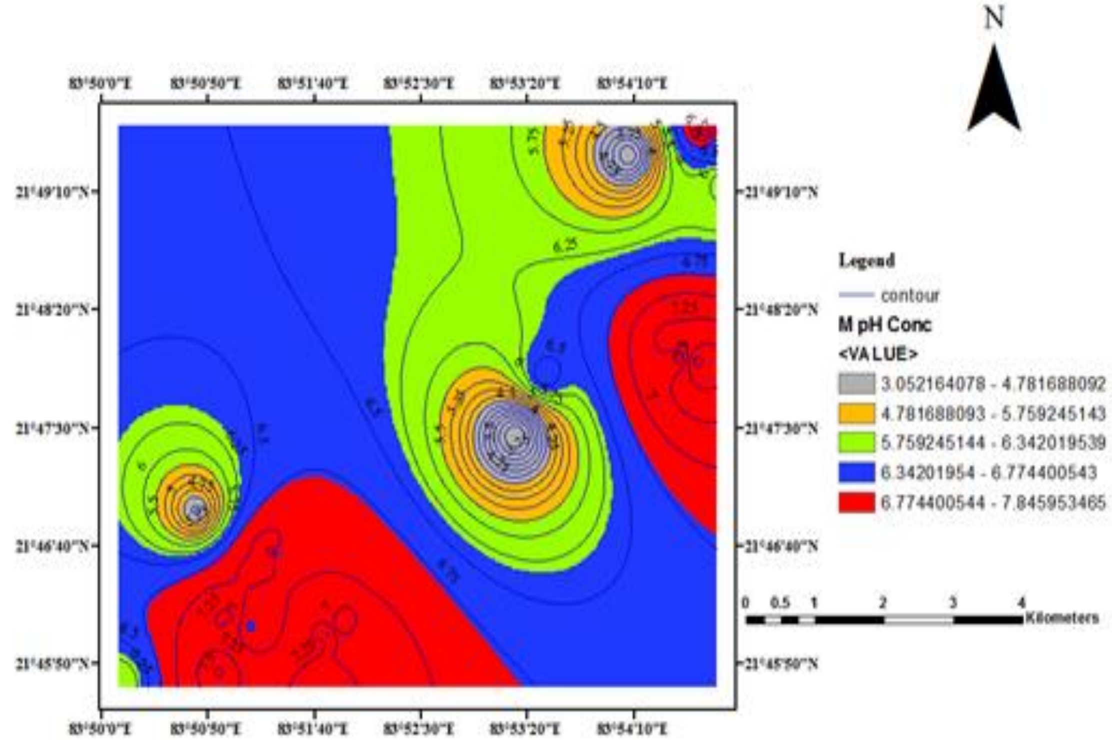

Figure 6.5: Monsoon Concentration contour map of pH in Ib valley area

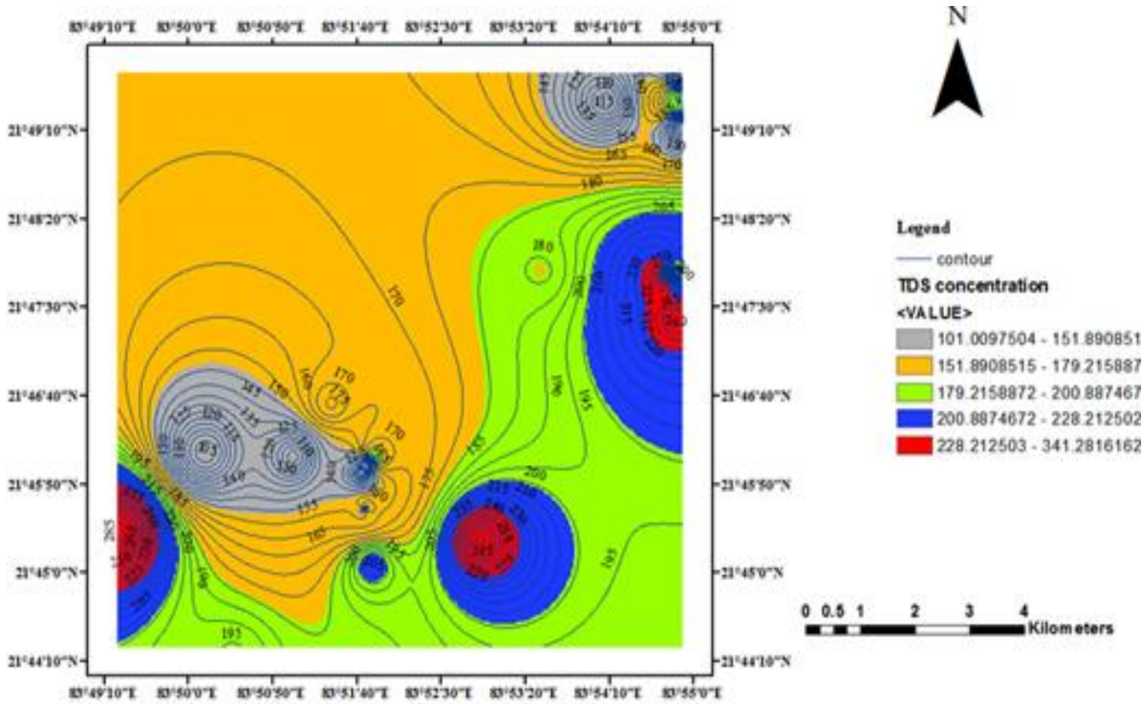

Figure 6.6: Pre-monsoon concentration contour map of TDS in Ib valley area

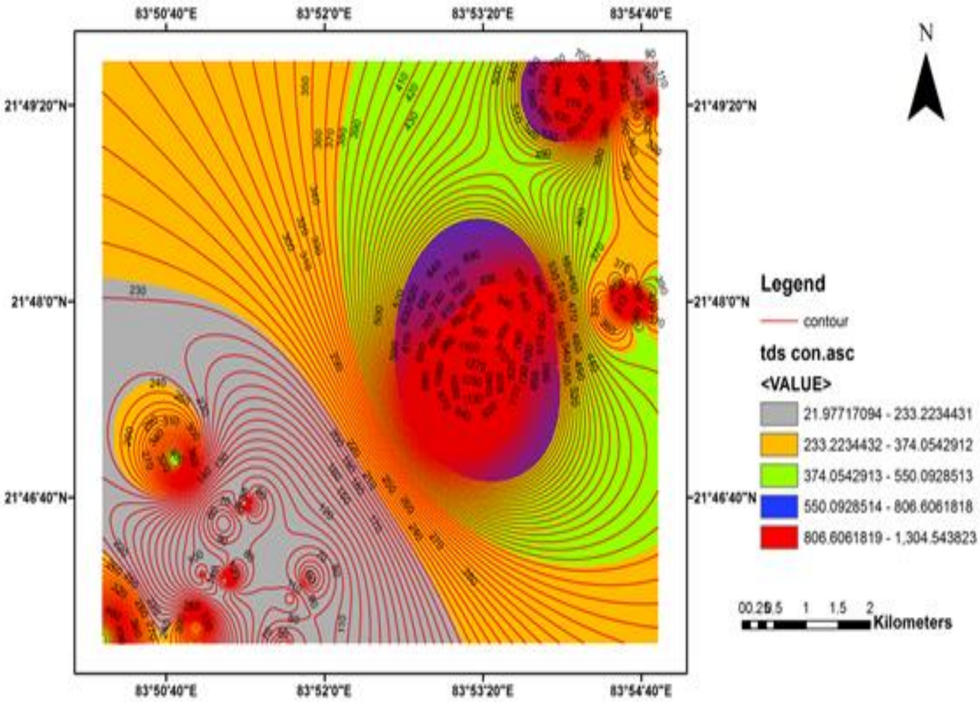

Figure 6.7: Monsoon concentration contour map of TDS in Ib valley

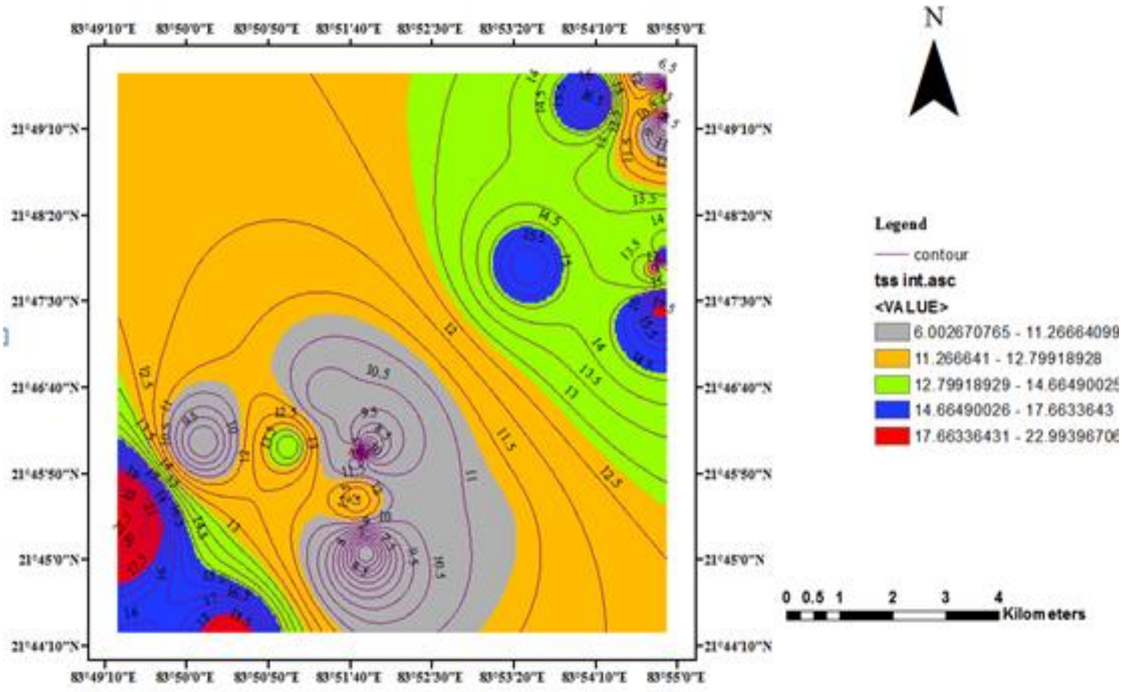

Figure 6.8: Pre-monsoon concentration contour map of TSS in Ib valley area

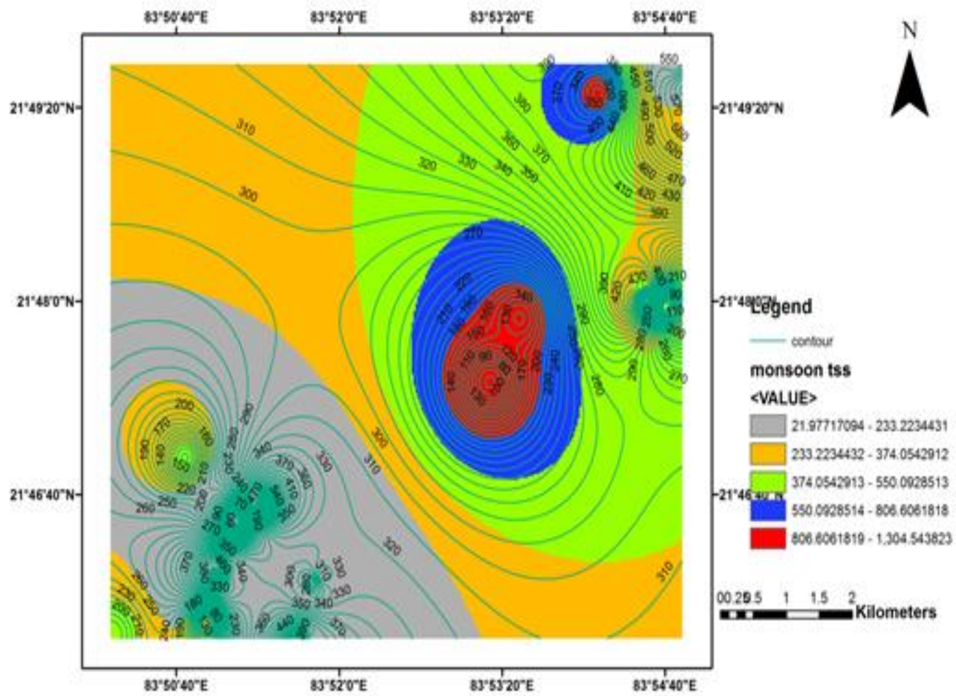

Figure 6.9: Monsoon concentration contour map of TSS in Ib valley

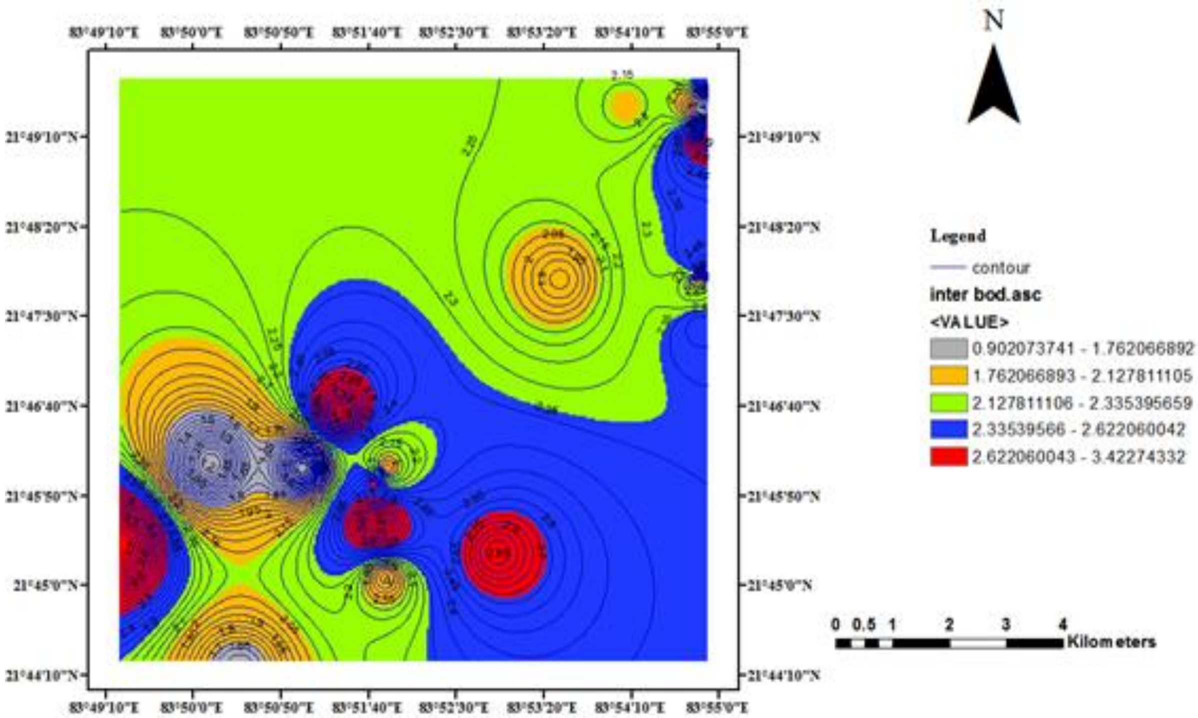

Figure 6.10: Pre-monsoon concentration contour map of BOD_3 in Ib valley area

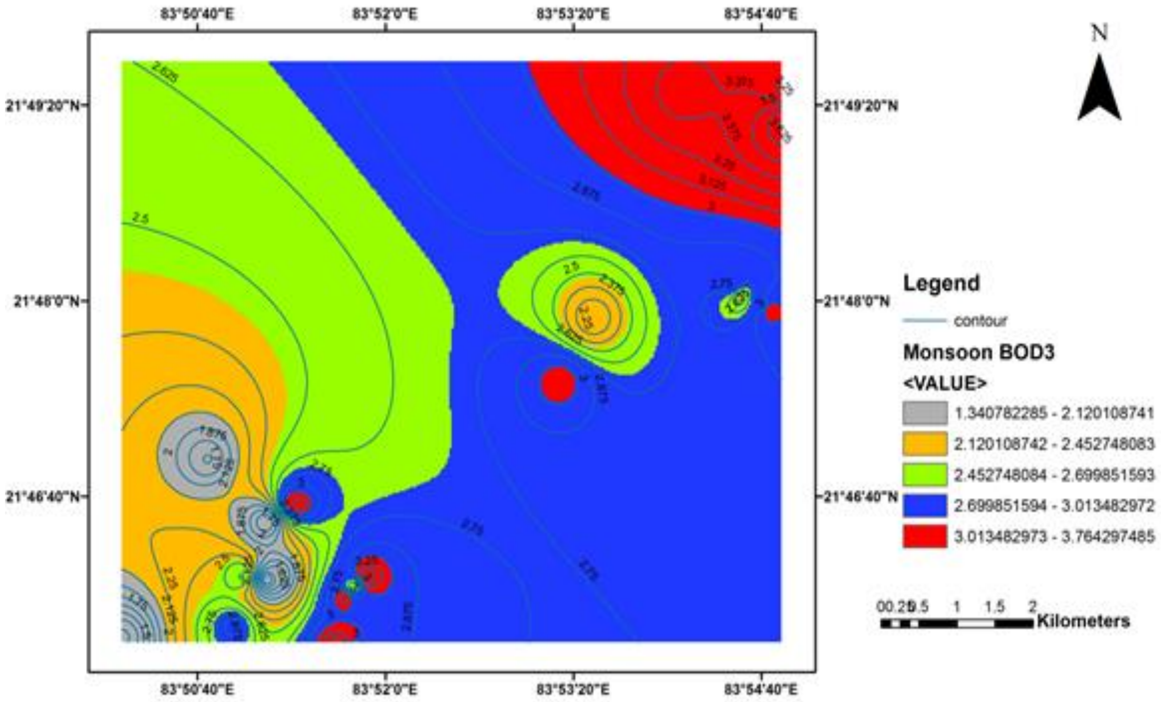

Figure 6.11: Monsoon concentration contour map of BOD_3 in Ib valley area

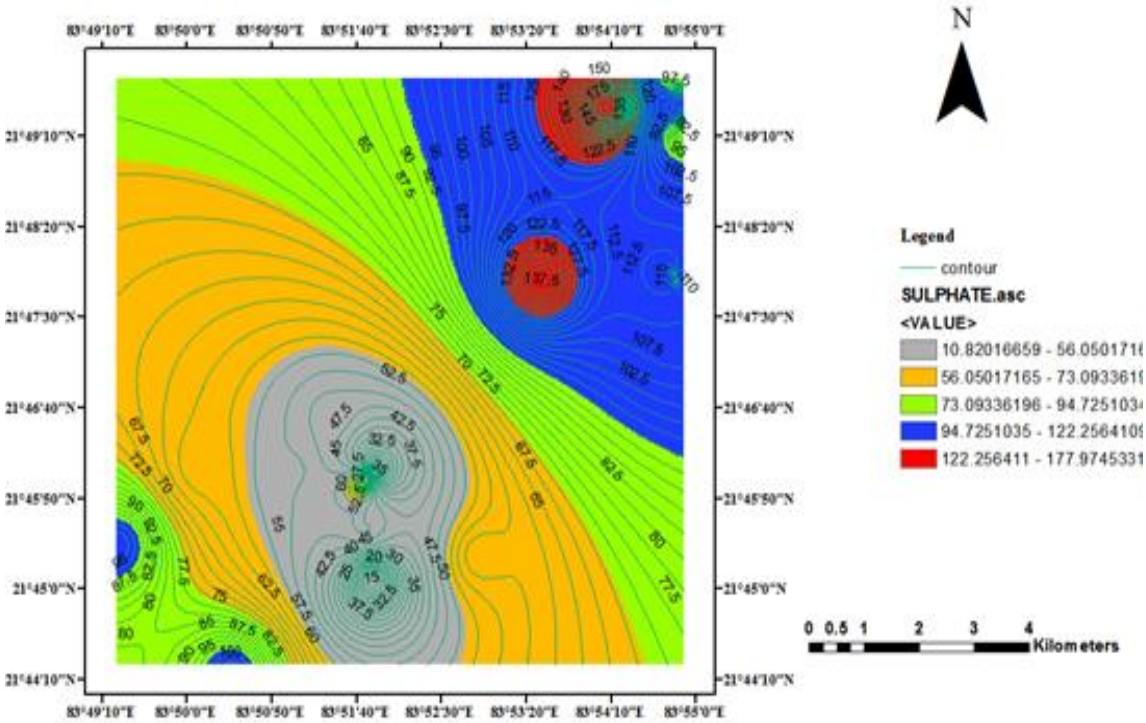

Figure 6.12: Pre-monsoon concentration contour map of Sulphate in Ib valley area

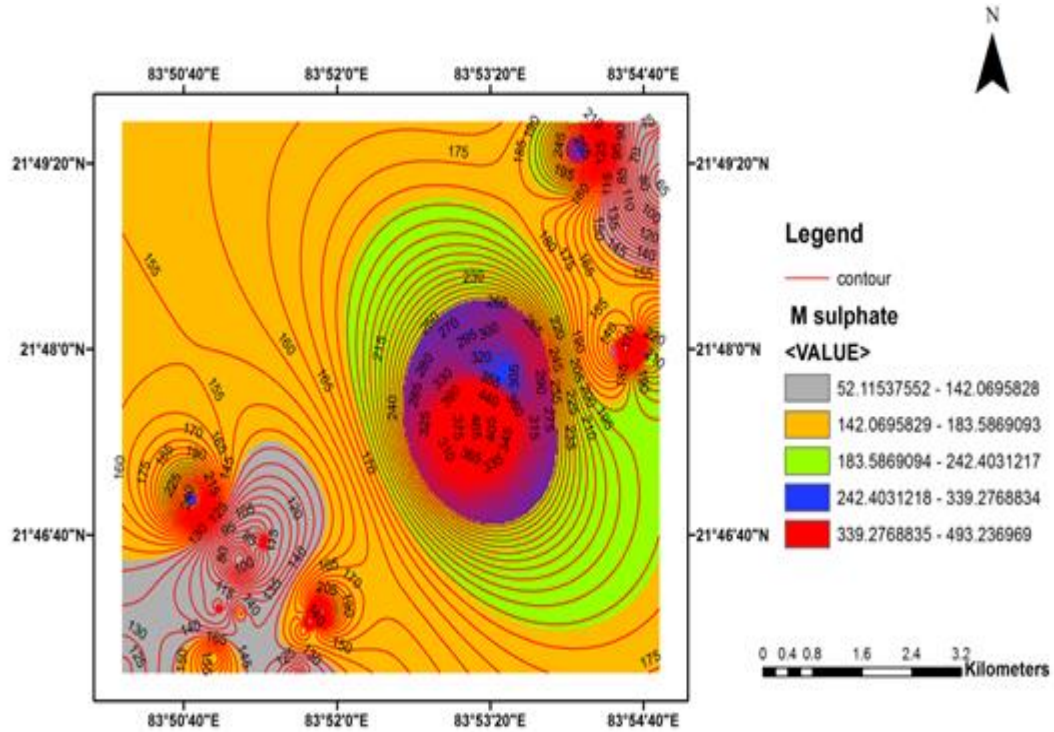

Figure 6.13: Monsoon concentration contour map of Sulphate in Ib valley area

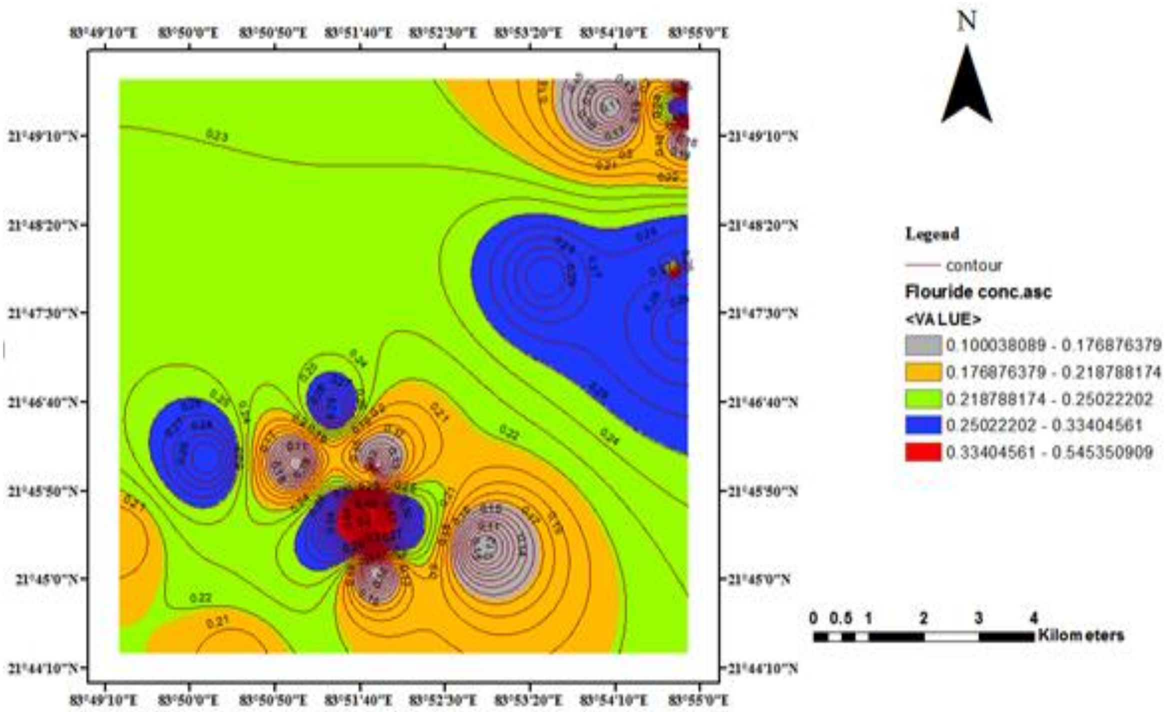

Figure 6.14: Pre-monsoon concentration contour map of Flouride in Ib valley area

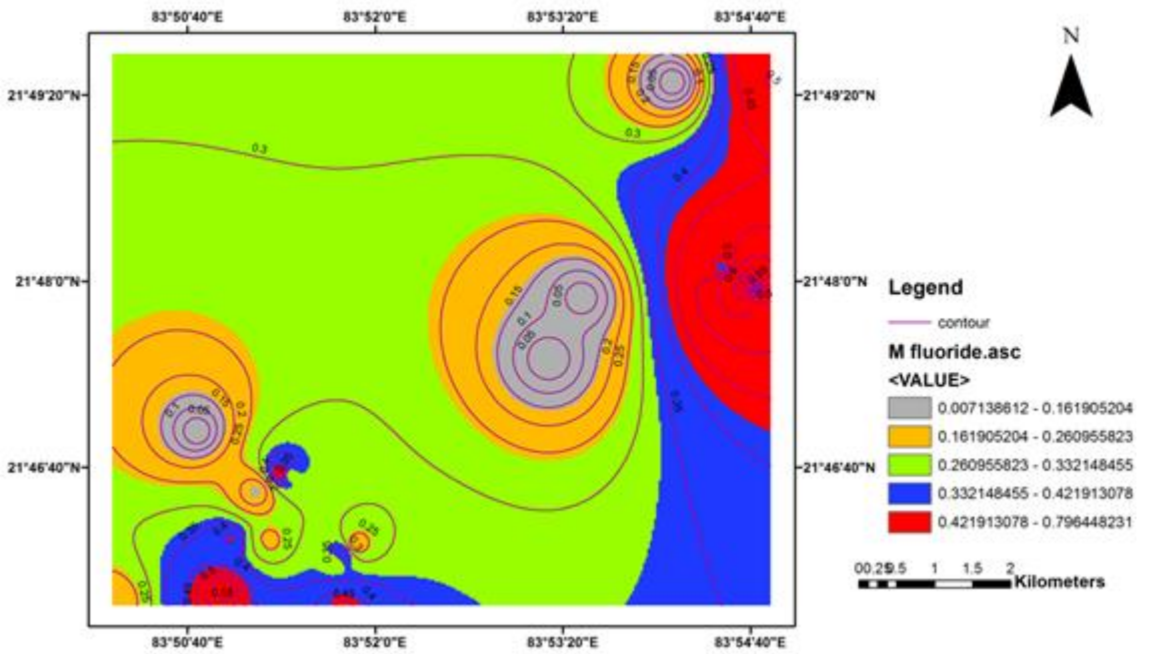

Figure 6.15: Monsoon concentration contour map of Flouride in Ib valley area

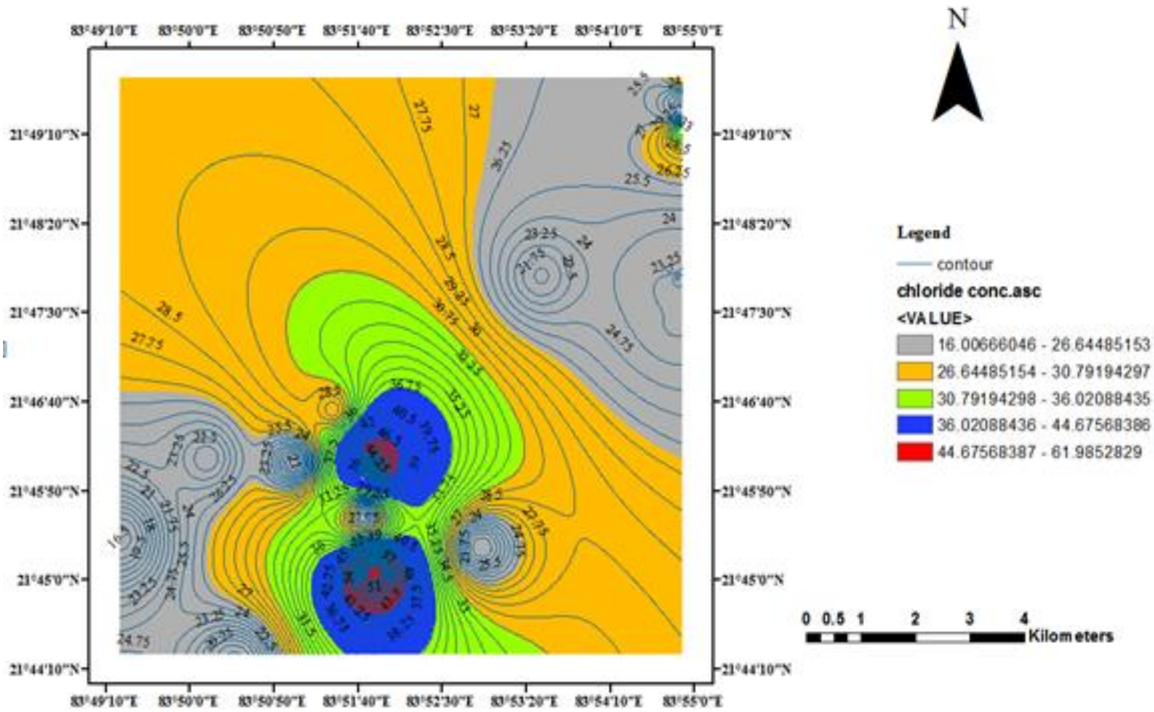

Figure 6.16: Pre-monsoon concentration contour map of Chloride in Ib valley area

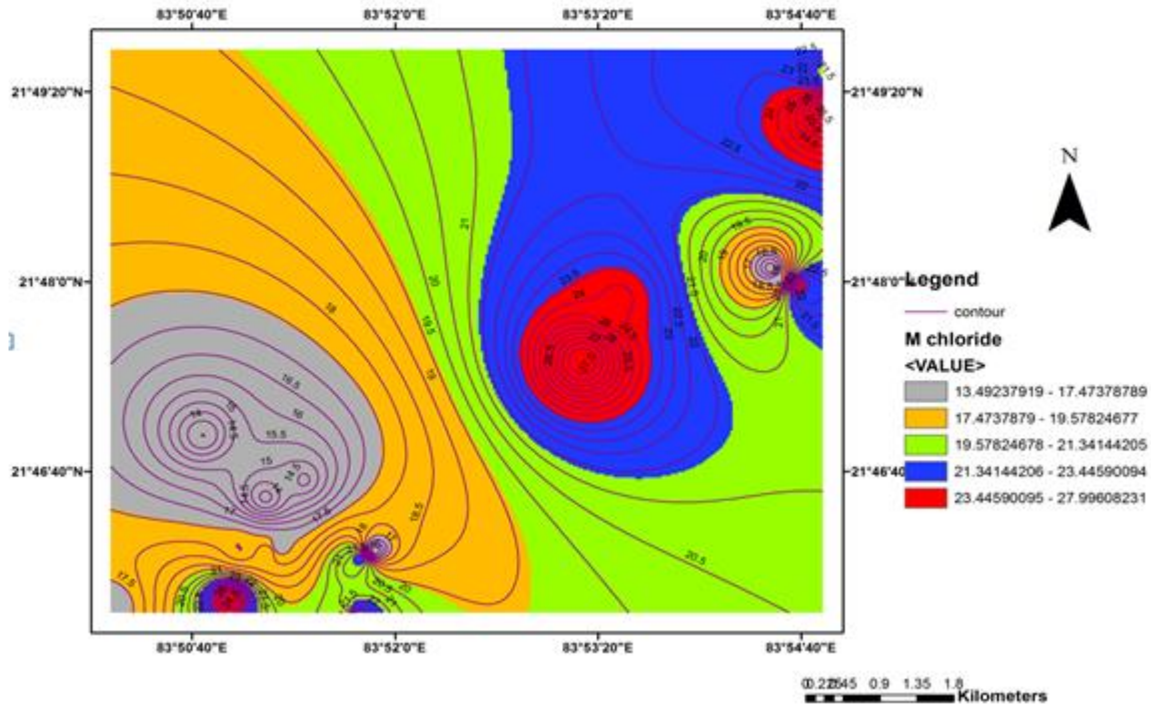

Figure 6.17: Monsoon concentration contour map of Chloride in Ib valley area

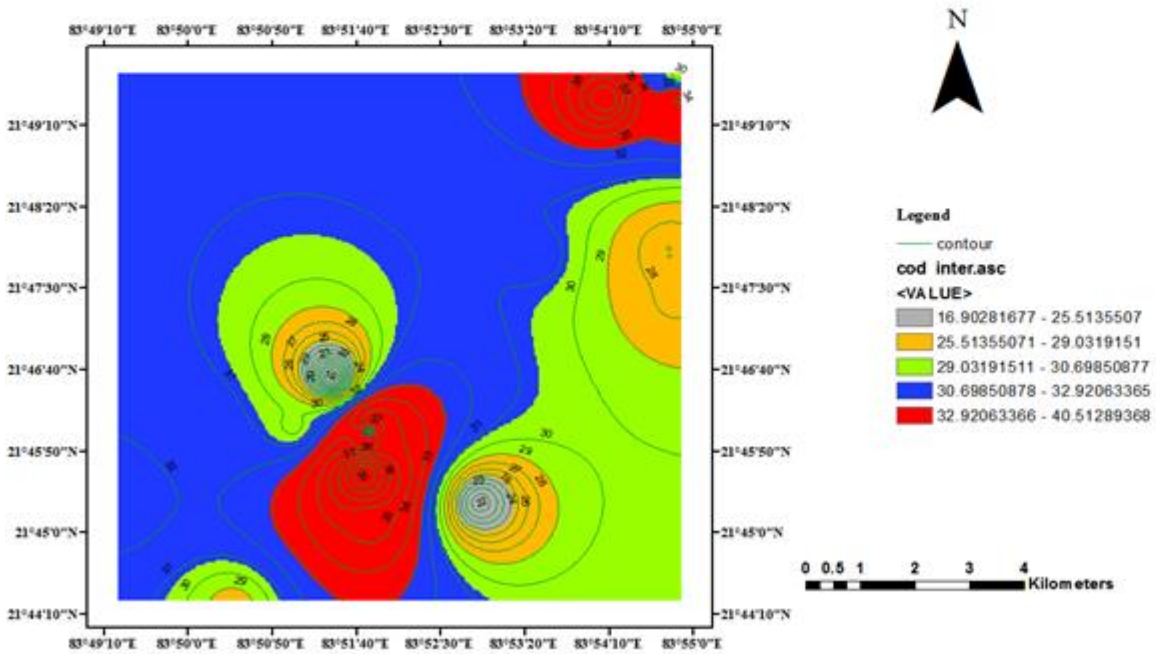

Figure 6.18: Pre-monsoon concentration contour map of COD in Ib valley area

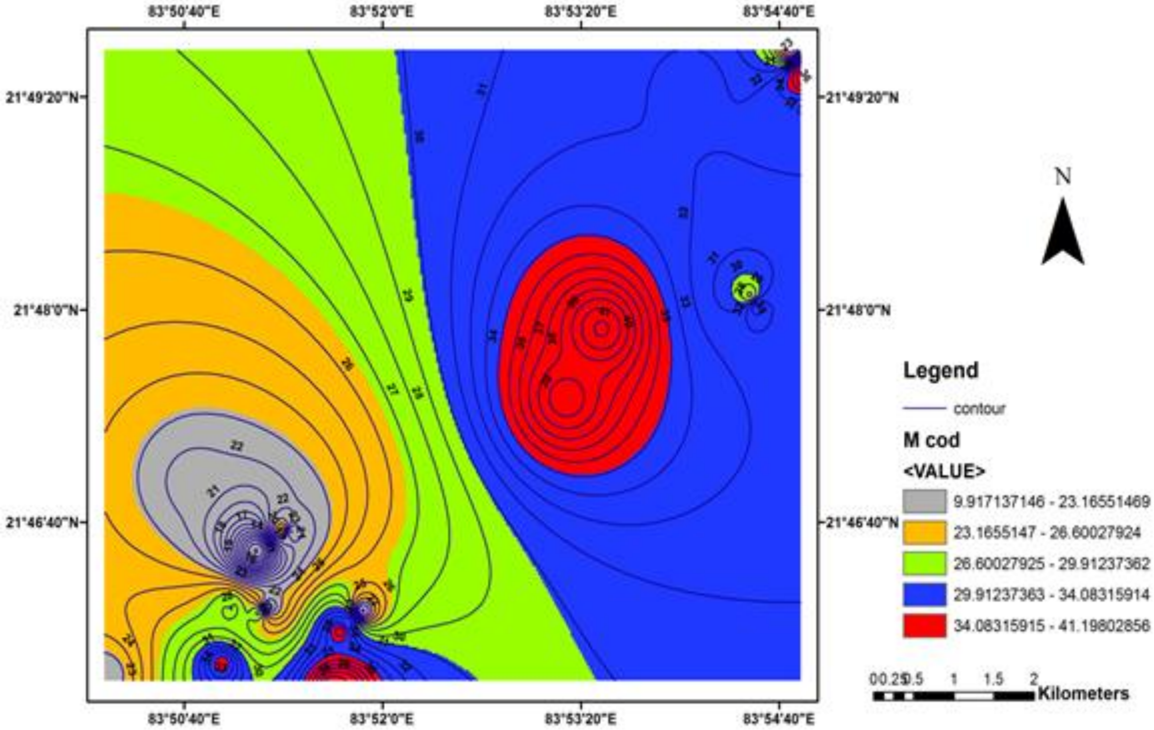

Figure 6.19: Monsoon concentration contour map of COD in Ib valley area

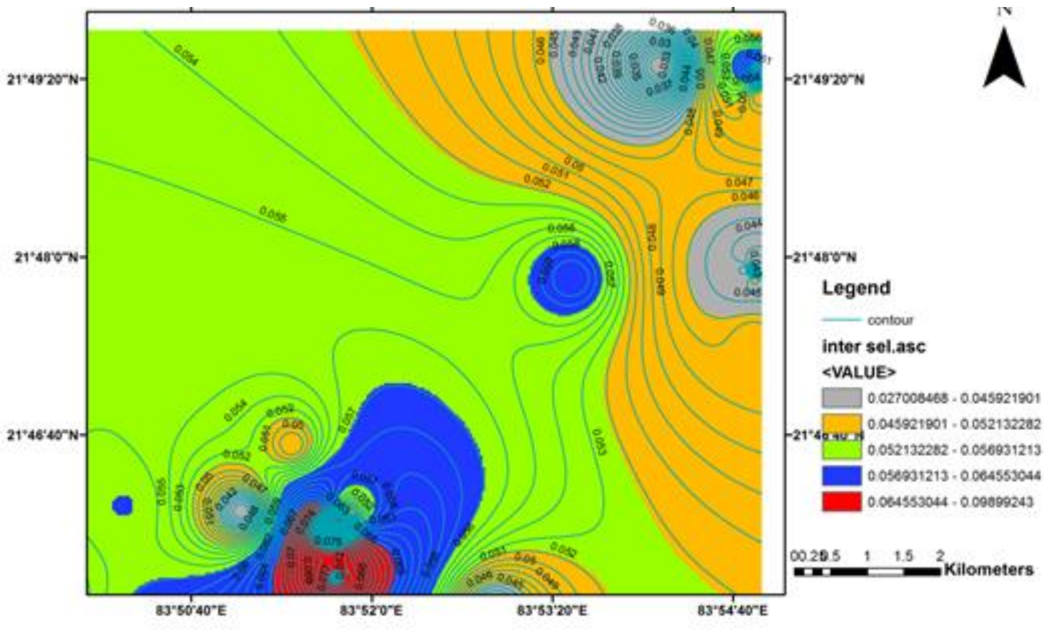

Figure 6.20 : Pre-monsoon concentration contour map of Selenium in Ib valley area

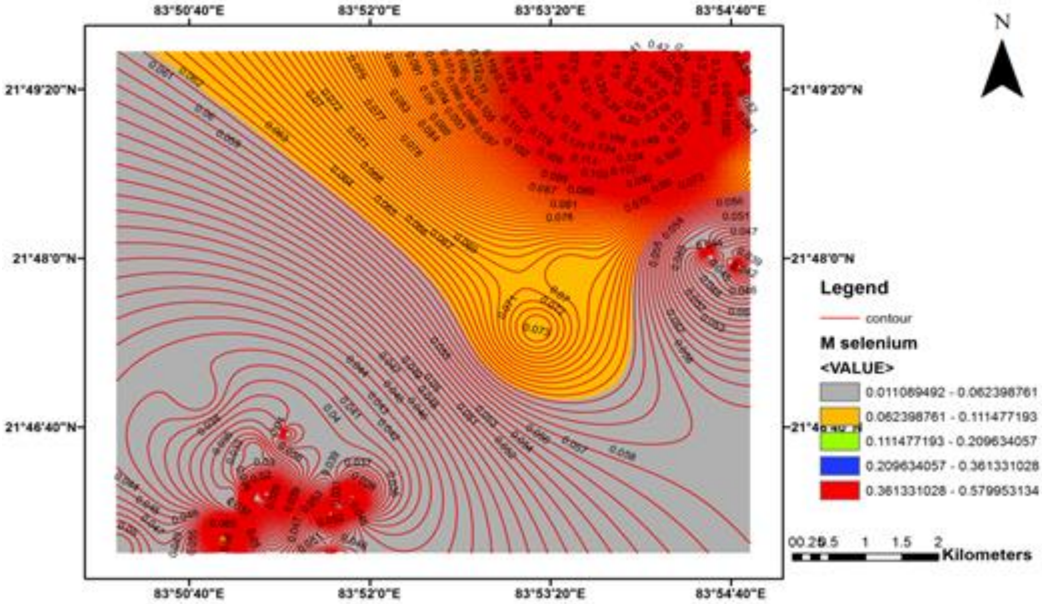

Figure 6.21: Monsoon concentration contour map of Selenium in Ib valley area

6.4 General Recommendations

Specific recommendations with respect to each mine has been presented in Section 4.7. However, some general recommendations applicable to all the opencast coal mines is being recommended which may be helpful for mine management to control the generation of excessive surface runoff and its adverse impacts.

All the existing mine sumps, garland drains, sedimentation ponds created on the surface should be de-silted before monsoon and record of the same should be maintained in the respective mine office. Whenever possible, the sumps may be deepened to accommodate more surface runoff quantity.

During face advance, if the sump has to be dewatered to win the bottom most seam, water should be transferred to the nearest existing sump, rather than discharging it outside the mine.

In order to avoid accidental entry of any person or cattle into the sedimentation ponds, proper fencing should be carried out. Warning signs should also be displayed near the water bodies along with their depth.

The mine management should continuously monitor the pH, total suspended solids, chemical oxygen demand, oil and grease, and the quantity of discharge particularly during the monsoon period, in order to ensure that contaminated water is not discharged to the nearby water bodies.

Provision of catch drain may be made around the coal stock area in order to protect the interaction of natural surface runoff with that of the coal stock. This will reduce the siltation of fine coal particles into the surrounding area. Runoff from the coal stock and CHP effluent should be channelized into mine sumps after settling ponds and should not be allowed to disperse and mix with general runoff.

6.5 Conclusions

As opencast mine projects are becoming large in terms of surface area, its impact on all three spheres of the environment viz. air, water and soil could also become severe, if proper preventive and control measures are not adopted. Surface runoff generated from the opencast coal mines is a cause of concern particularly during the monsoon. It is desirable that all the mines create adequate storage space within the mine premises to store the surface runoff generated during the monsoon rather than releasing it outside contaminating the nearby water bodies. Moreover, the stored water could be used to meet the water demand of the mine for the whole year. This will avoid unnecessary pumping of water from the natural water bodies, which could be utilized for other gainful applications. In fact, in some cases it has been found that the water could be used for drinking purposes with some preliminary treatment. The mine authorities may also explore the possibility for construction of a number of recharge pits beyond the zone of influence. This will also help in recharging the natural ground water bodies in the mining region.

In general, the water quality of mine sump of most of the opencast mines are found to be within permissible limit for utilization in industrial activities like dust suppression, firefighting, irrigation of plantation, washing of HEMMs etc. However, it has been observed that there is increase in concentration of parameters like TSS, Oil and Grease in water samples collected in the monsoon season compared to the pre-monsoon quality. Most of the mine sump water is nearly neutral to alkaline in nature. However, the mine water of Lajkura sump and Samaleswari south sump show strongly acidic characteristics. Proper scientific study may be carried out for control of acidic drainage in these areas. In most of the samples, the heavy metal concentrations are within the permissible limit as compared to effluent standards prescribed under Environment Protection Rules, 1986. But a large amount of selenium has been observed in some of the water samples, which have several health impacts on the human beings, animals as well as aquatic life. Selenium concentration beyond the permissible limit has the potential to cause hepatotoxicity and gastrointestinal disturbances, dermatologic effects such as nail and hair loss, and dermatitis. It may cause reproductive failure and birth defects in animals. However, the high concentration of Selenium is directly linked to the pH of the water samples, the concentration being the maximum in the acidic discharges. Therefore, adequate attention must be given for the prevention and control of acid mine drainage.

6.6 Scope for Further Research

The current research can be further investigated due to its genuine significance. It has wide scope for exploring. However, it will require better funding. Some of the potential research areas have been outlined below.

Though problem of acid mine drainage has been noticed in few instances, proper scientific study should be done to find the sources of acid mine drainage and for selection of a cost effective neutralizing material.

It takes a long time for the settlement of the solids in the sedimentation ponds. In some cases alum dosing is being carried out. However, a cost effective coagulant must be selected based on coagulation analysis.

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Dissemination

List of Publications

1. Gleekia,A. M. G D., **Pradhan, D. S**., and Sahu, H. B. (2016). "Impacts of iron ore mining on water quality and the environment in Liberia, Geominetech: *The Indian Mineral and Mining Industry Journal Vol 03 Iss-No. 02,April-June/ENTMS 2016,pp. 11- 15*.
2. Sahoo B., Sahu H.B. and **Pradhan D. S.** (2016). Geotechnical, geochemical and mineralogical characterization of coal mine waste for restoring environment in opencast mines. *Proceedings of International conference on recent trends in engineering and material sciences. Publ. no 10IC2633*. JNU, Rajashtan.
3. **Pradhan. D. S**., Sahu H.B, and Sahoo B. Study of Surface Runoff and its Impact from Opencast Coal Mines in the Ib Valley Basin, Odisha (Communicated)